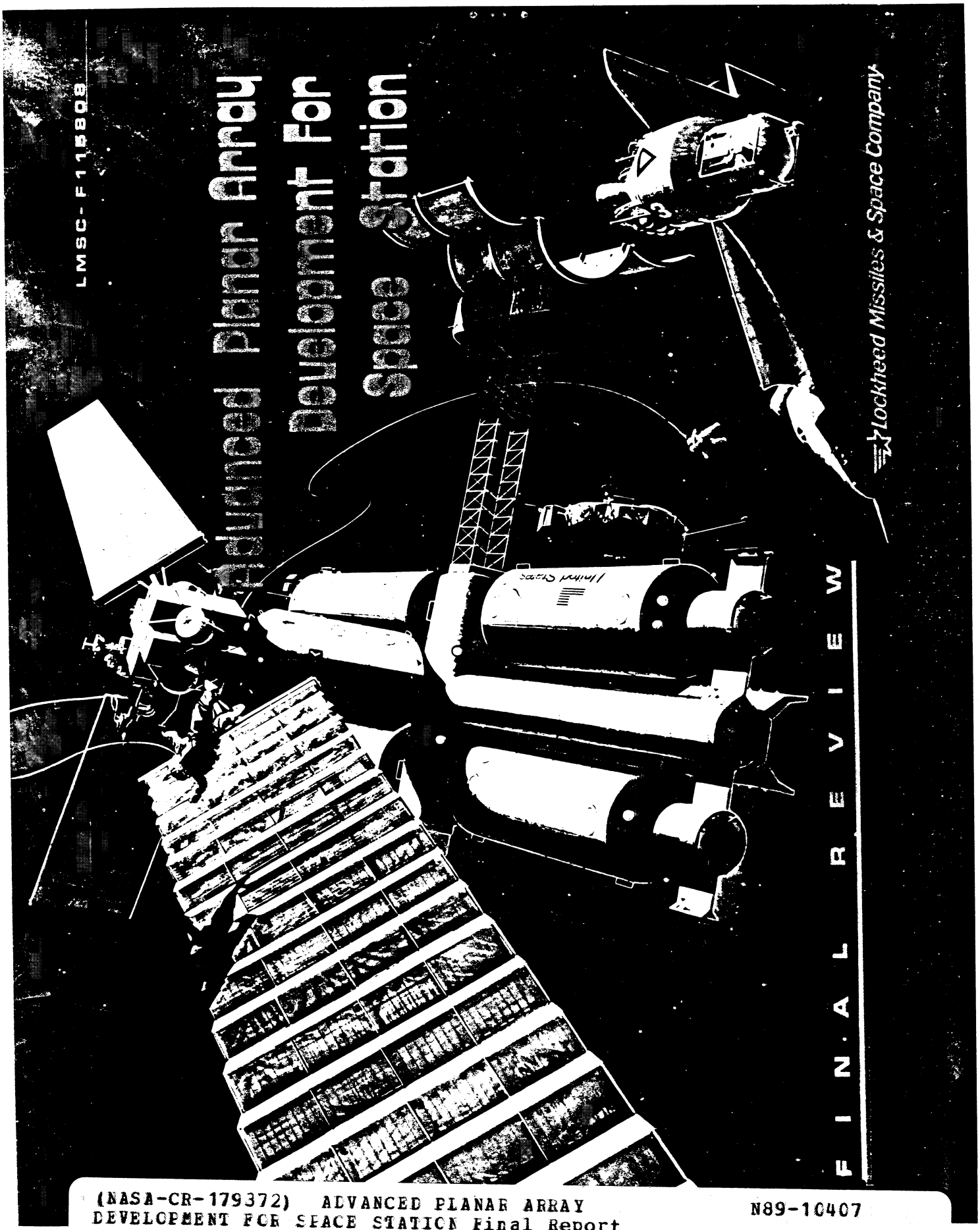

ADVANCED PLANAR ARRAY DEVELOPMENT FOR SPACE STATION

FINAL ORAL REPORT

MAY 19, 1987

SUBMITTED TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER

CONTRACT NO. NAS8-36419

AGENDA

- OBJECTIVES
- APPROACH
  - TASK DESCRIPTION
  - PROJECT FLOW DIAGRAM
  - SCHEDULE
- PROGRESS
  - SUPERSTRATE AND CONVENTIONAL MODULE DESIGN (TASK 1.0)
  - PROCESS DEVELOPMENT
  - FABRICATION AND TEST (TASK 2.0)
    - THERMAL CYCLE TESTING (TASK 2.1)
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- SUMMARY
- ADDITIONAL WORK

OBJECTIVES

- DEVELOP PROCESS FOR MANUFACTURING SUPERSTRATE ASSEMBLIES
- DEMONSTRATE SUPERSTRATE TECHNOLOGY THROUGH FABRICATION AND TEST
- DEVELOP AND ANALYZE A PRELIMINARY SOLAR ARRAY WING DESIGN
- FABRICATE A WING SEGMENT BASED ON THE WING DESIGN

TASK DESCRIPTION

TASK 1.0 WING DESIGN AND ANALYSIS
- * 1.1 DEVELOP PRELIMINARY DESIGN OF A SOLAR ARRAY WING
- 1.2 DETAIL DESIGN
- 1.3 ENVIRONMENT/ANALYSIS
  - 1.3.1 GROUND HANDLING ENVIRONMENT
  - 1.3.2 SHUTTLE ORBITER LAUNCH AND REENTRY ENVIRONMENTS
  - 1.3.3 LOW EARTH ORBIT OPERATIONAL ENVIRONMENT
  - 1.3.4 RESULTANT ELECTRICAL PERFORMANCE

TASK 2.0 MODULE FABRICATION AND TESTS
- * 2.1 THERMAL CYCLE TESTING
- * 2.2 THERMAL BALANCE TESTING
- * 2.3 15" X 50" DELIVERABLE MODULE

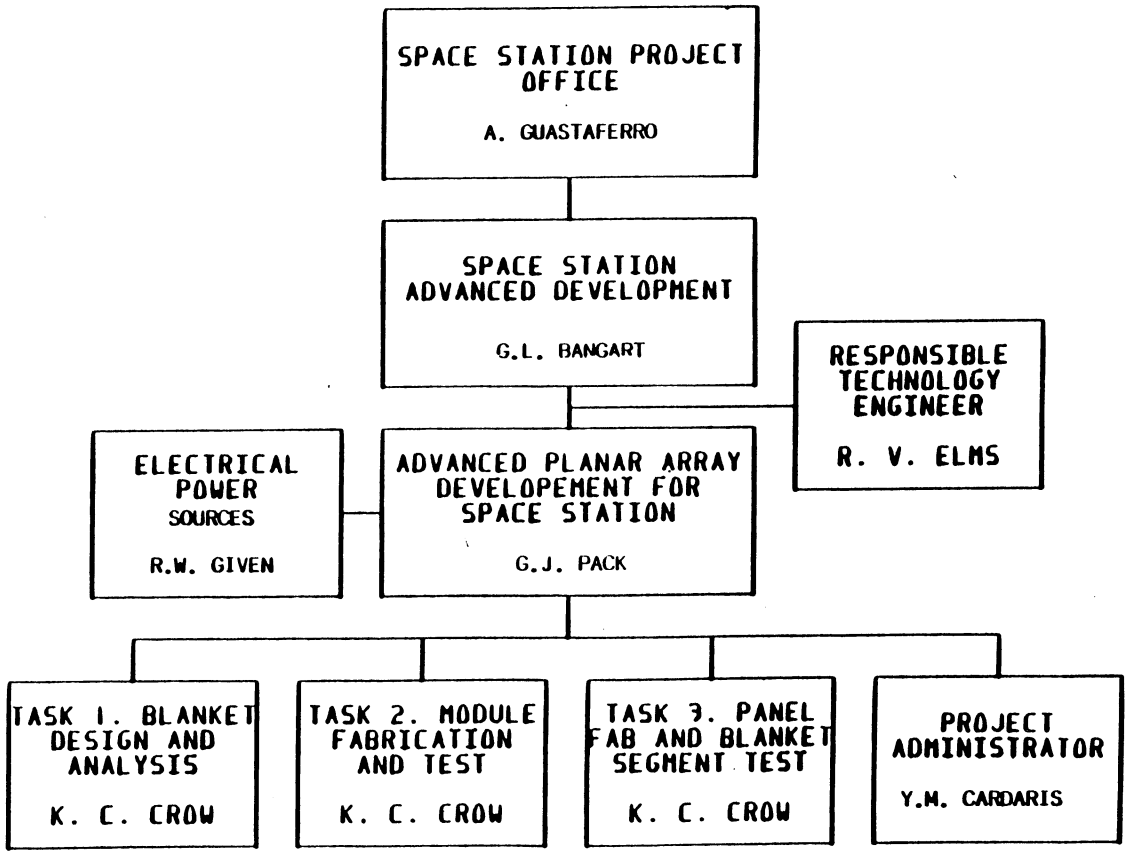
TASK 3.0 PANEL FABRICATION AND TESTING
- 3.1 FABRICATE SOLAR ARRAY PANELS
- 3.2 DEVELOPMENT TESTING
- 3.3 STOWAGE AND SMALL SEGMENT TESTING

TASK 4.0 DELIVERABLES
- 4.1 FINAL REPORT
- 4.2 ALL MODULES TESTED IN TASK 2.0
- * 4.3 15" X 50" MSFC TEST MODULE
- 4.4 WING SEGMENT AND DEPLOYER

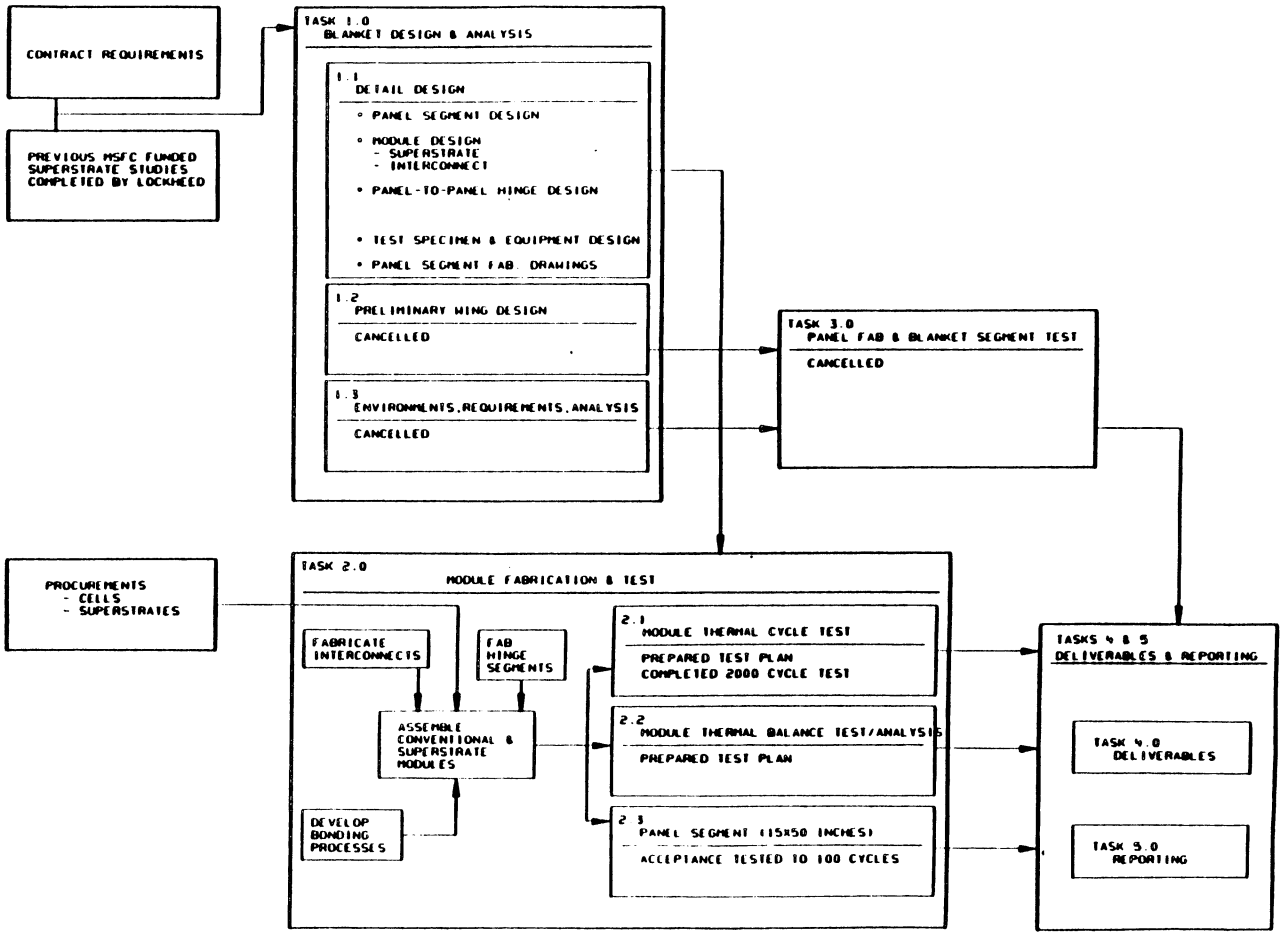
TASK 5.0 REPORTING
- * 5.1 MONTHLY PROGRESS REPORTS AND MANAGEMENT (FINANCIAL) REPORTS
- * 5.2 MID-TERM ORAL PRESENTATIONS
- * 5.3 FINAL ORAL PRESENTATION
- 5.4 FINAL COMPREHENSIVE REPORT

* COMPLETED

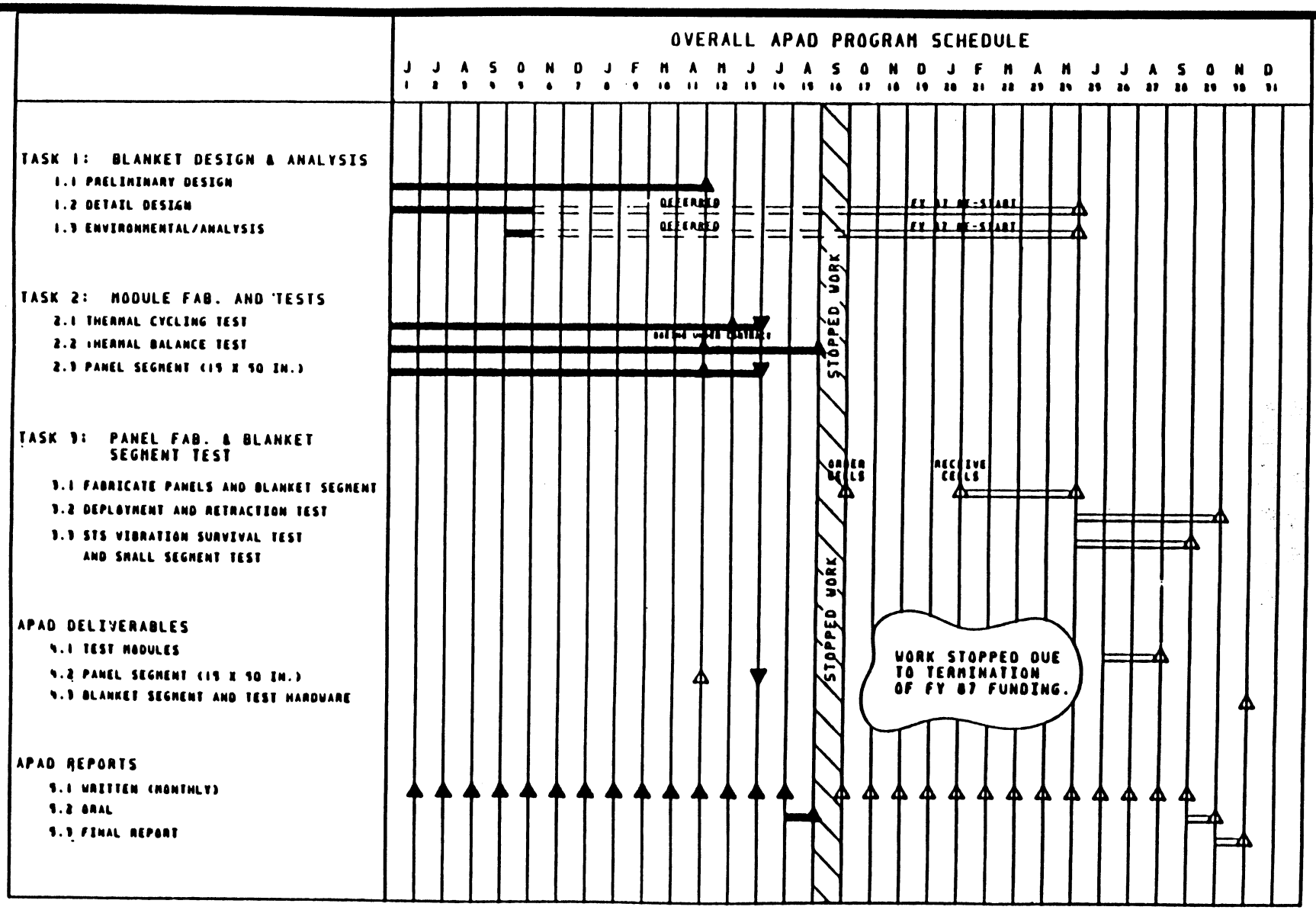
PROJECT ORGANIZATION



PROJECT FLOW DIAGRAM



PROGRAM SCHEDULE



MODULE ASSEMBLY - SUPERSTRATE VS CONVENTIONAL

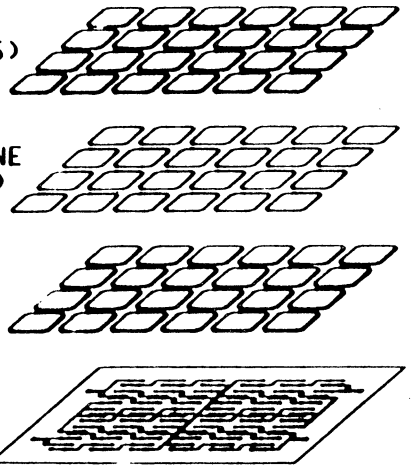
CONVENTIONAL MODULE

COVERSLIDES
(MICROSHEET GLASS)

DC 93-500 SILICONE
ADHESIVE (LIQUID)

SOLAR CELL ASSYS
5.9 X 5.9 CM W.A.
(24 CELLS)

COPPER/KAPTON
INTERCONNECT



SUPERSTRATE MODULE

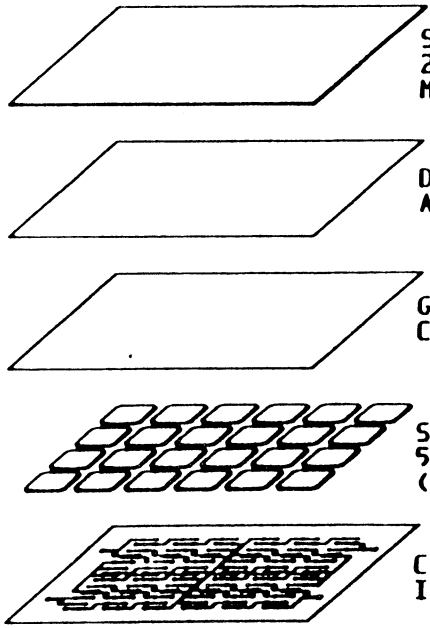
SUPERSTRATE
20 MIL OR 9 MIL
MICROSHEET GLASS

DC 93-500 SILICONE
ADHESIVE (LIQUID)

GLASS SCRIM
CLOTH

SOLAR CELL ASSYS
5.9 X 5.9 CM W.A.
(24 CELLS)

COPPER/KAPTON
INTERCONNECT

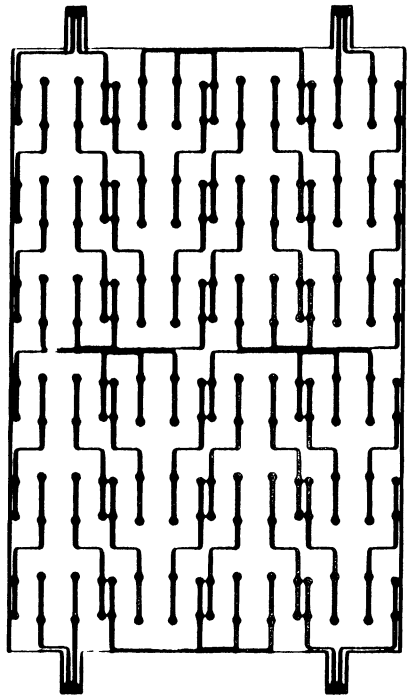


LARGE AREA SOLAR CELL DESCRIPTION

- 5.9 X 5.9 CM ROUNDED CORNERS (8 MILS THICK)
- WRAPAROUND "N" CONTACT
- GRIDDED "P" CONTACT
- 2 OHM-CM MATERIAL
- ELECTRICAL EFFICIENCY 13.2% AMO @ 25°C
- BACK SURFACE TREATMENT
  - OPTICAL COATING TO ENHANCE TRANSMISSION
  - ALUMINUM 2000-4000 ANGSTROM REFLECTOR

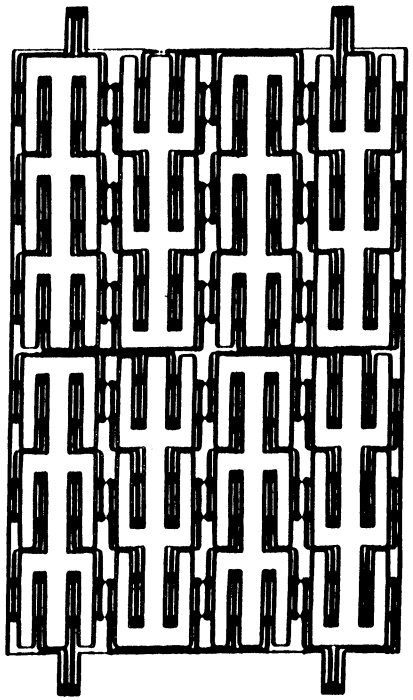
MODULE INTERCONNECTS

THERMAL CYCLE TEST



FULL KAPTON

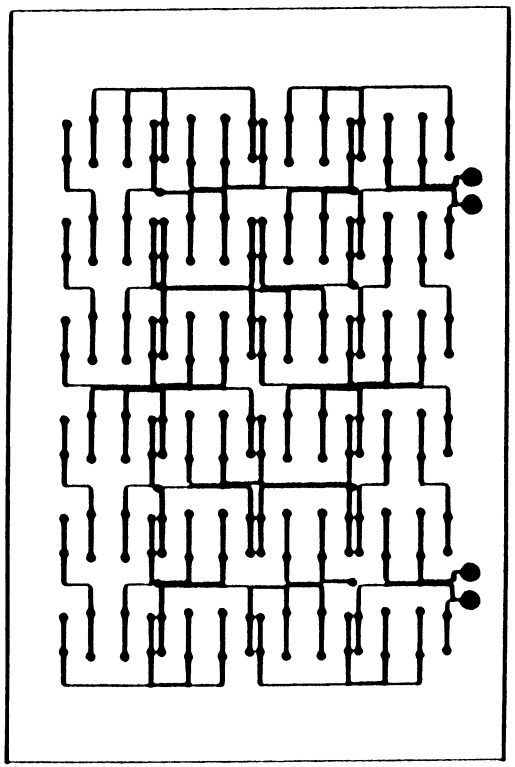
THERMAL CYCLE TEST
PANEL SEGMENT



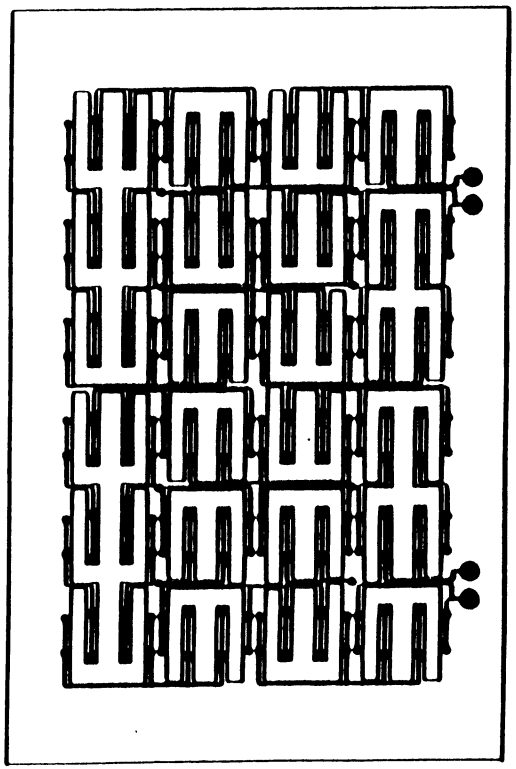
CUT-AWAY KAPTON

MODULE INTERCONNECTS

THERMAL BALANCE TEST MODULES

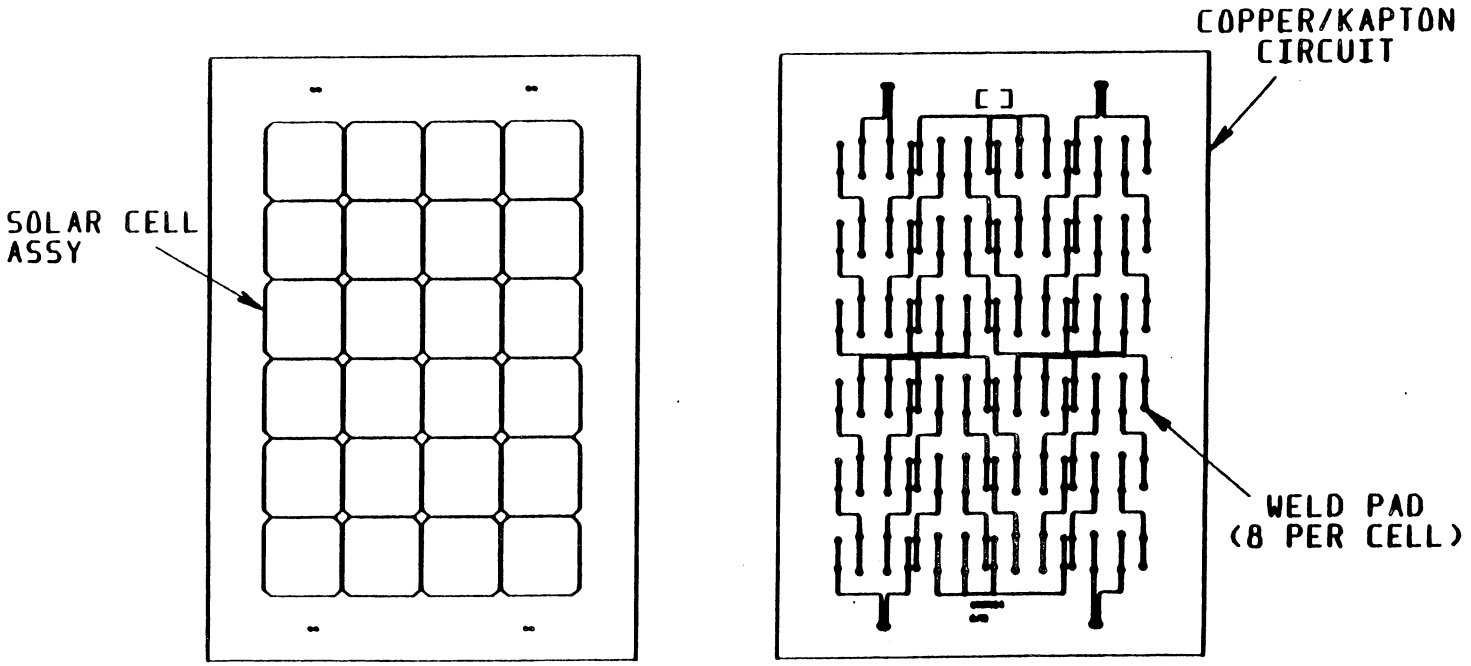


FULL KAPTON

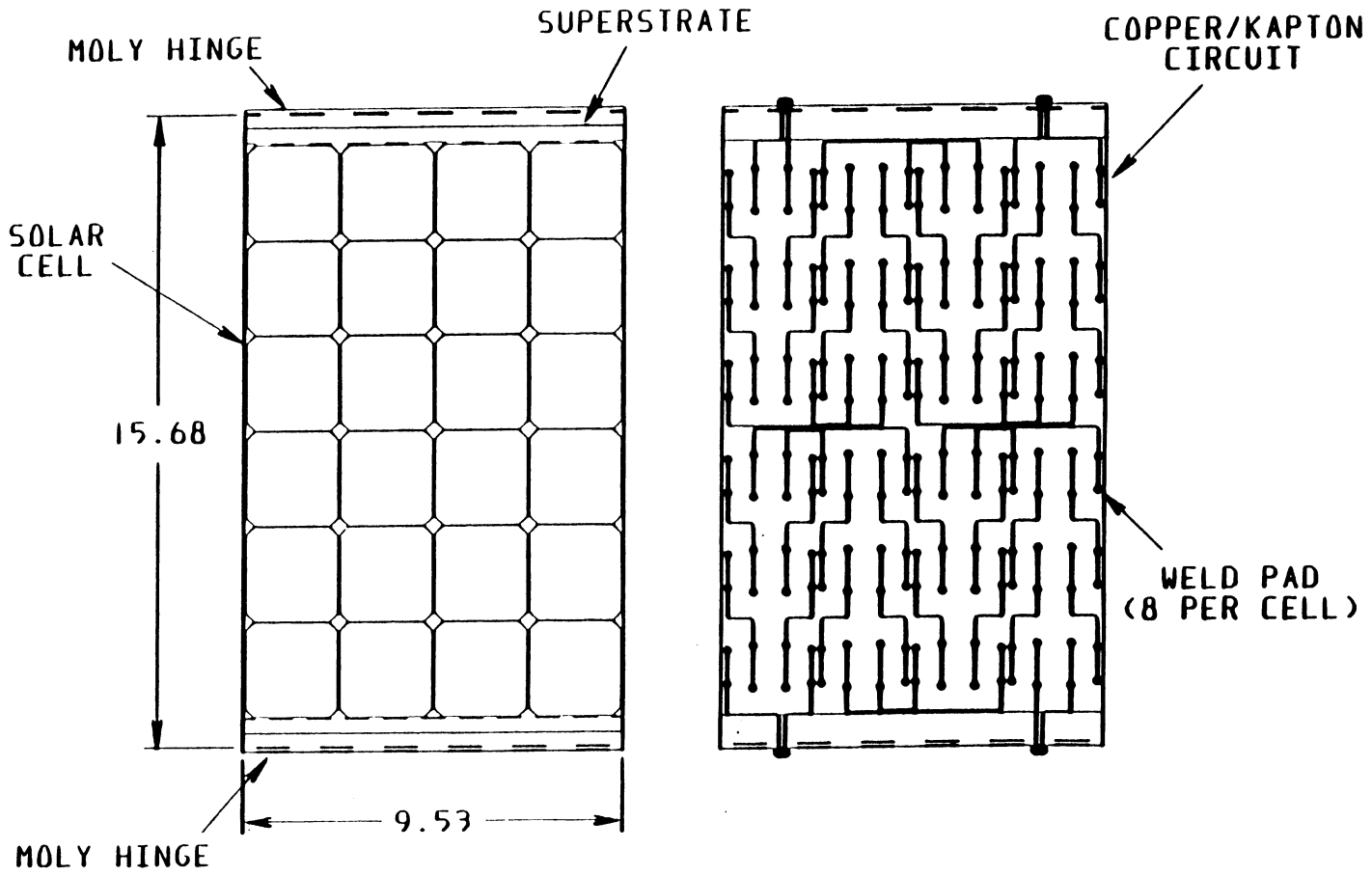


CUT-AWAY KAPTON

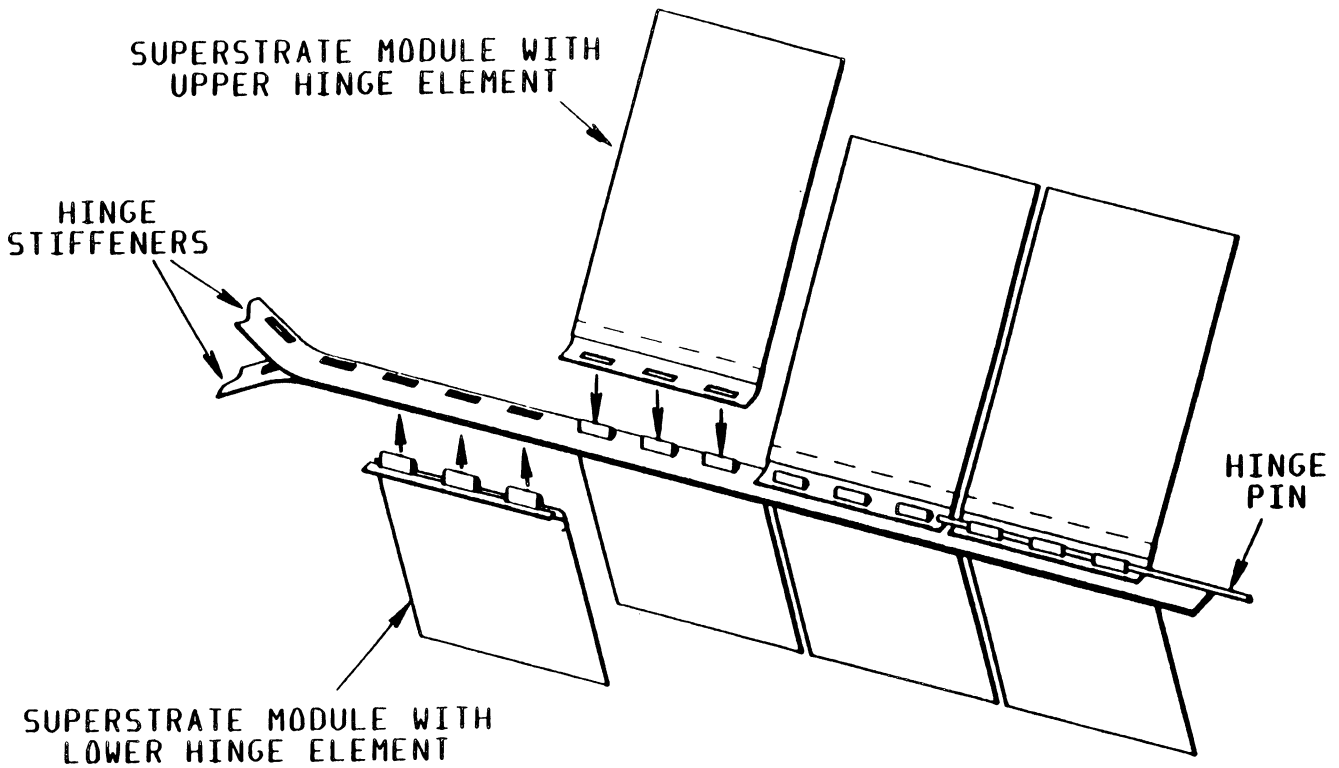
CONVENTIONAL MODULE ASSEMBLY



SUPERSTRATE MODULE ASSEMBLY



SUPERSTRATE HINGE



CONVENTIONAL LAYUP SEQUENCE

1. MANUFACTURE SOLAR CELL ASSEMBLIES.

2. PLACE SOLAR CELL ASSEMBLIES IN WELDING FIXTURE.

3. PLACE COPPER/KAPTON INTERCONNECT OVER SOLAR CELL ASSEMBLIES AND ALIGN WELD PADS TO ELECTRICAL CONTACTS.

4. TAPE COPPER/KAPTON INTERCONNECT TO SOLAR CELLS WITH LOW TACK TAPE.

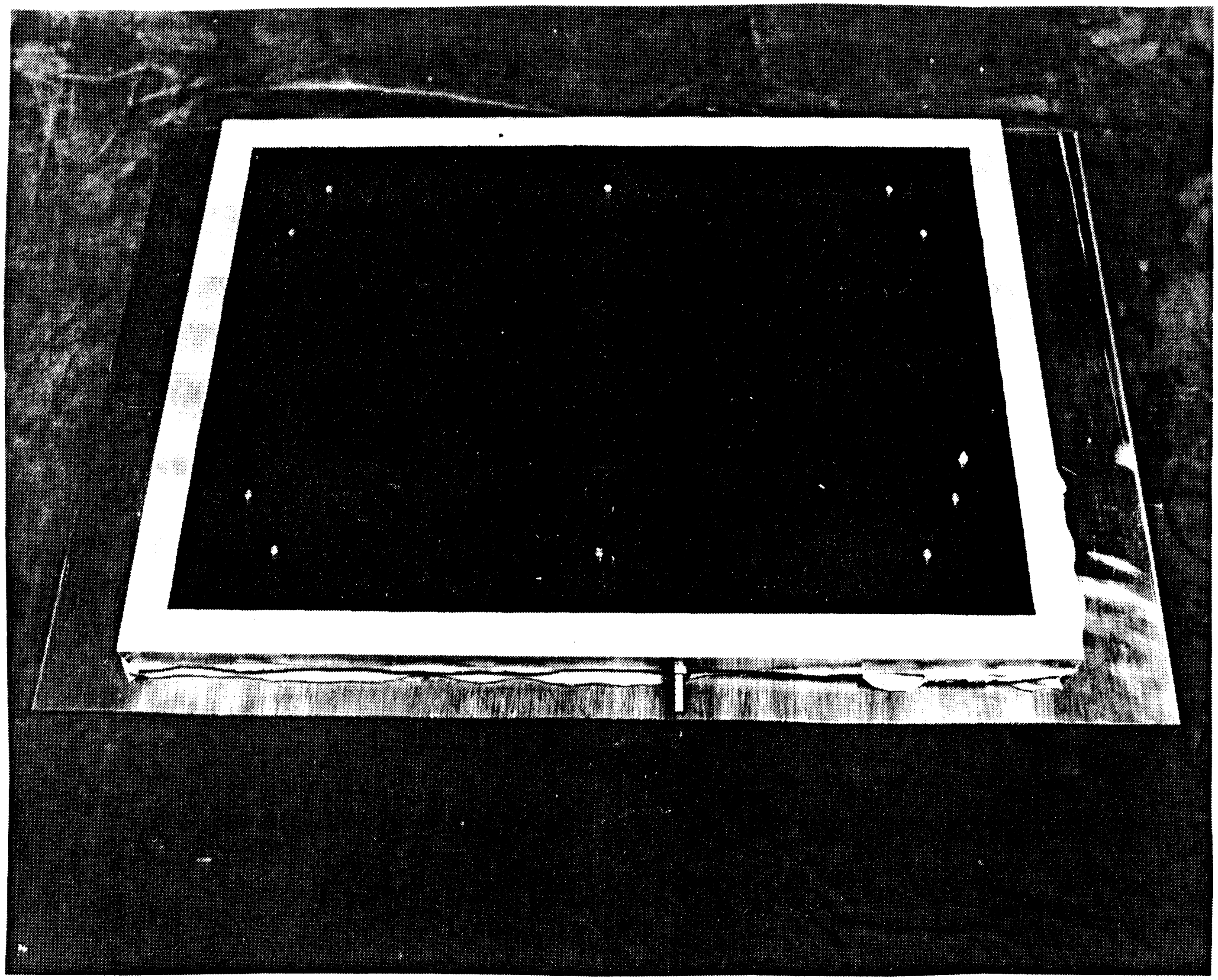
5. WELD CIRCUIT TO SOLAR CELLS AND REMOVE TAPE.

6. ELECTRICAL TEST AND INSPECT.

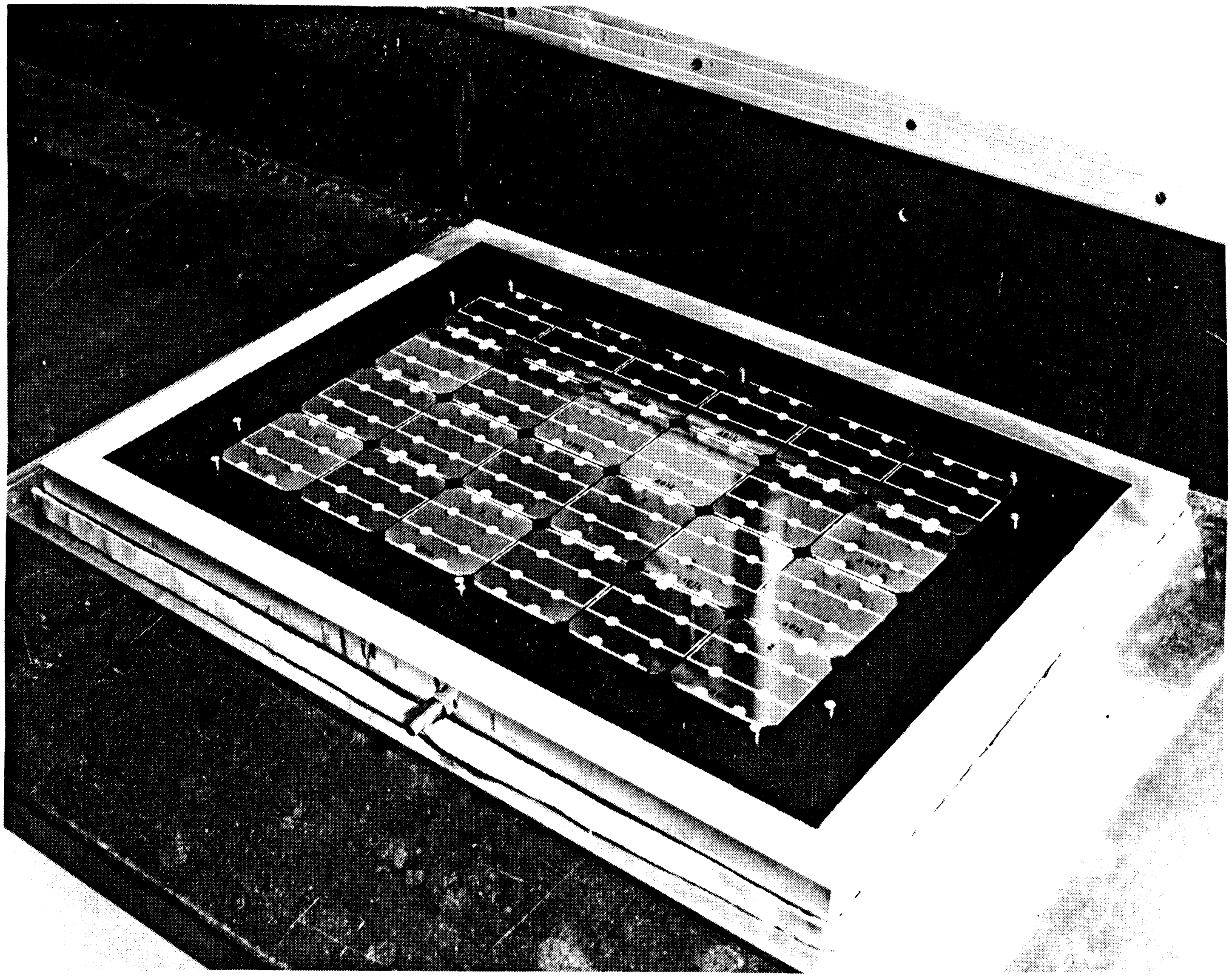
SUPERSTRATE LAYUP SEQUENCE

1. 9.56" X 15.00" X .020" OR 9.56" X 15.00" X .009" MICROSHEET
2. APPLY GLASS SCRIM CLOTH AND DC 93-500 ADHESIVE TO MICROSHEET GLASS
3. PRE-CURE GLASS, SCRIM, AND ADHESIVE IN OVEN.
4. PLACE SOLAR CELLS IN SUPERSTRATE BONDING TOOL (ELECTRICAL CONTACTS FACING UP).
5. MASK SOLAR CELLS WITH LOW TACK TAPE.
6. FLIP SOLAR CELLS OVER AND POSITION IN SUPERSTRATE BONDING TOOL.
7. APPLY DC 93-500 ADHESIVE IN CENTER OF SOLAR CELLS.
8. PLACE PREPARED GLASS ON SOLAR CELLS AND SPREAD ADHESIVE WITH ROLLER.
9. CURE IN OVEN.
10. BOND HINGES TO SUPERSTRATE GLASS USING DC 93-500 ADHESIVE
11. WELD COPPER/KAPTON INTERCONNECT TO ELECTRICAL CONTACTS OF SOLAR CELL
12. ELECTRICAL TEST AND INSPECT.

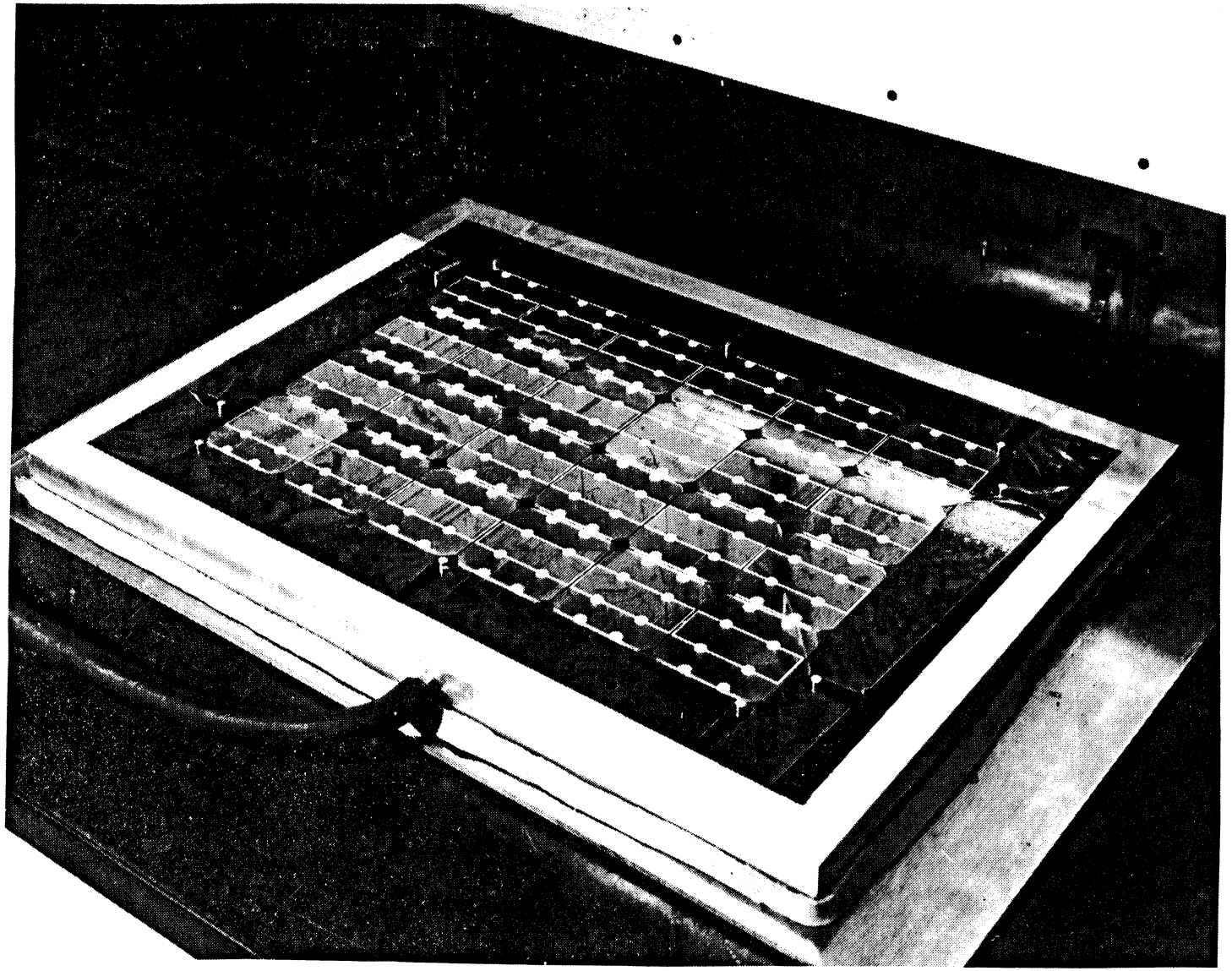
SUPERSTRATE BONDING TOOL



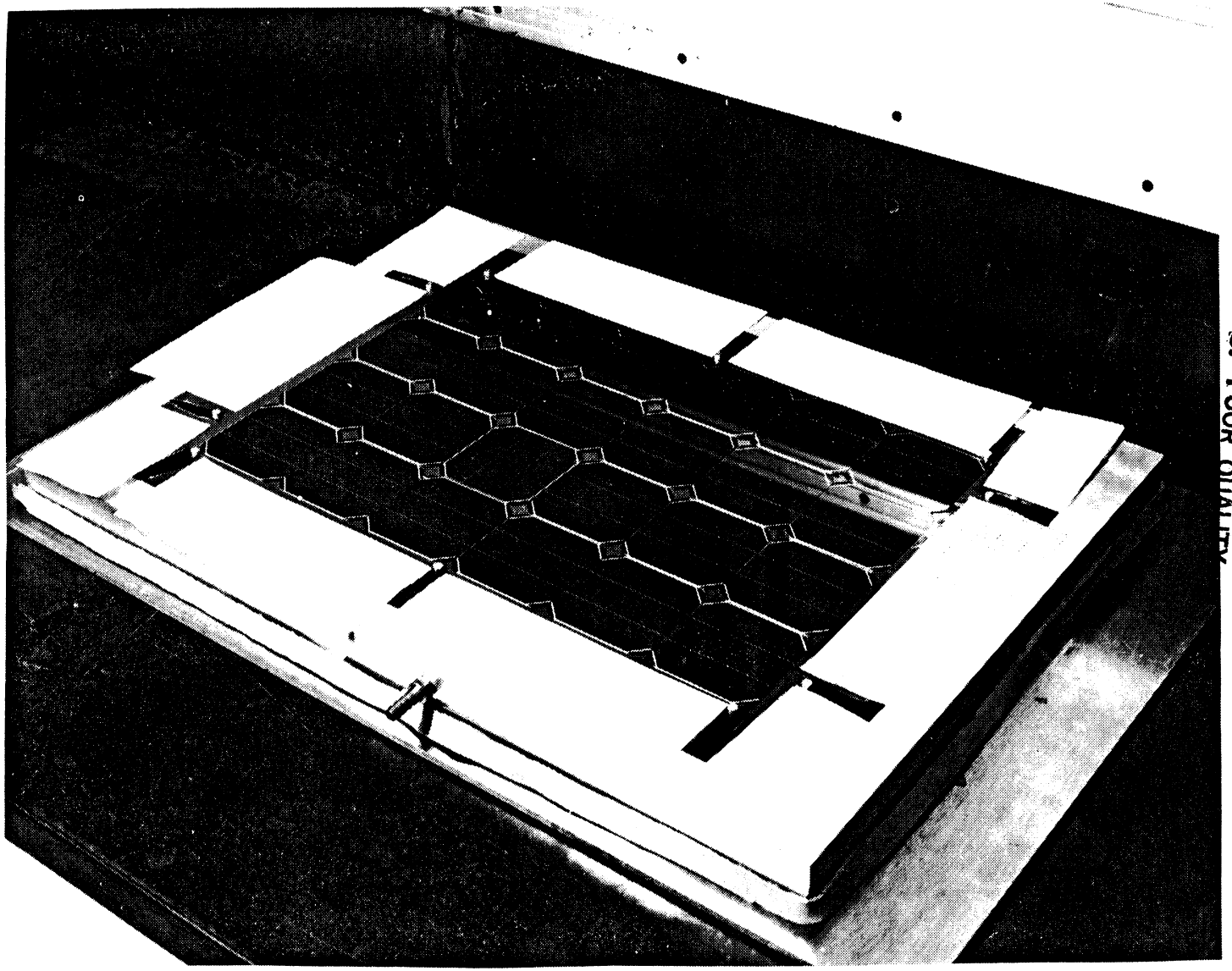
SOLAR CELLS POSITIONED IN BONDING TOOL



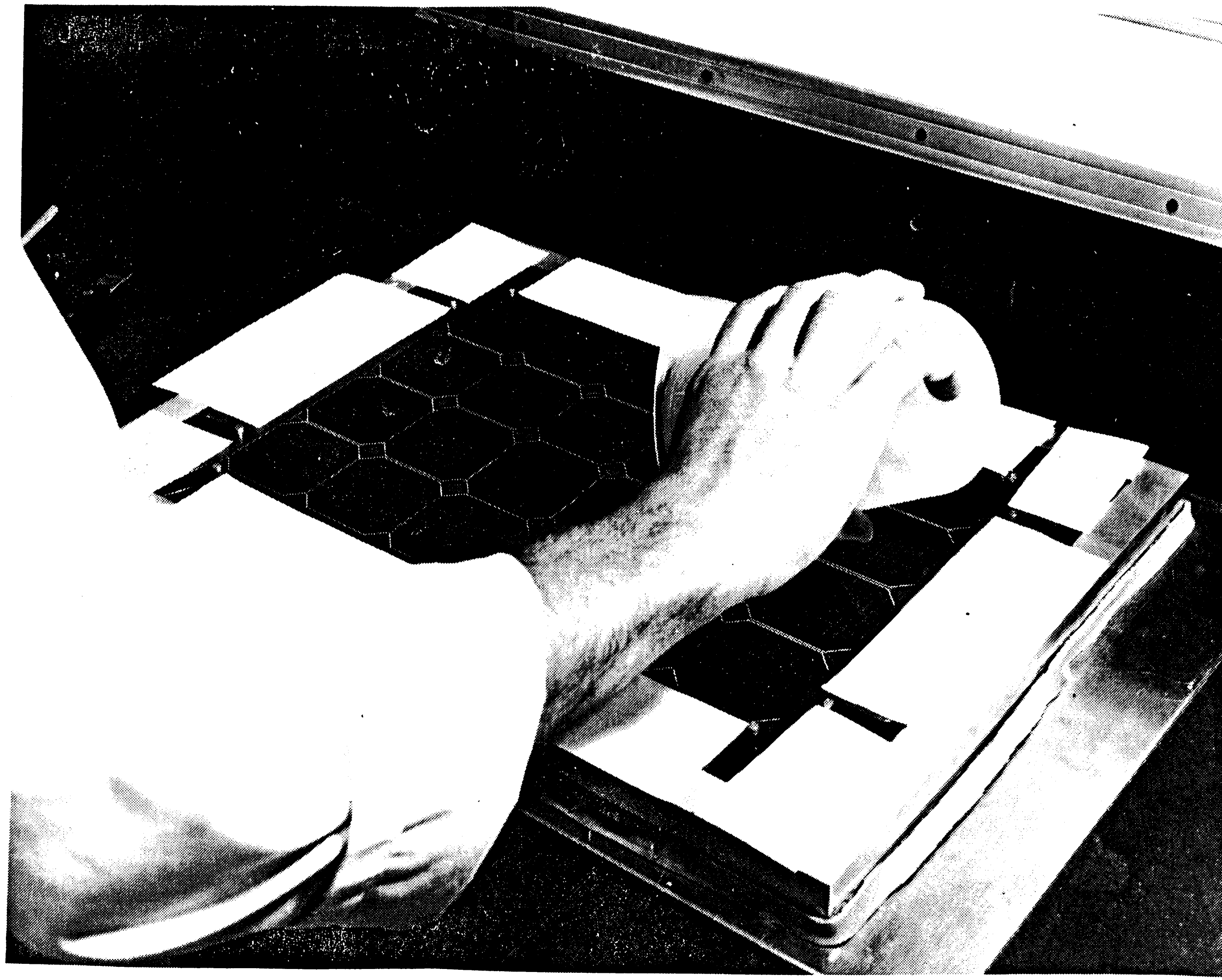
MASKED SOLAR CELLS USING LOW TACK TAPE



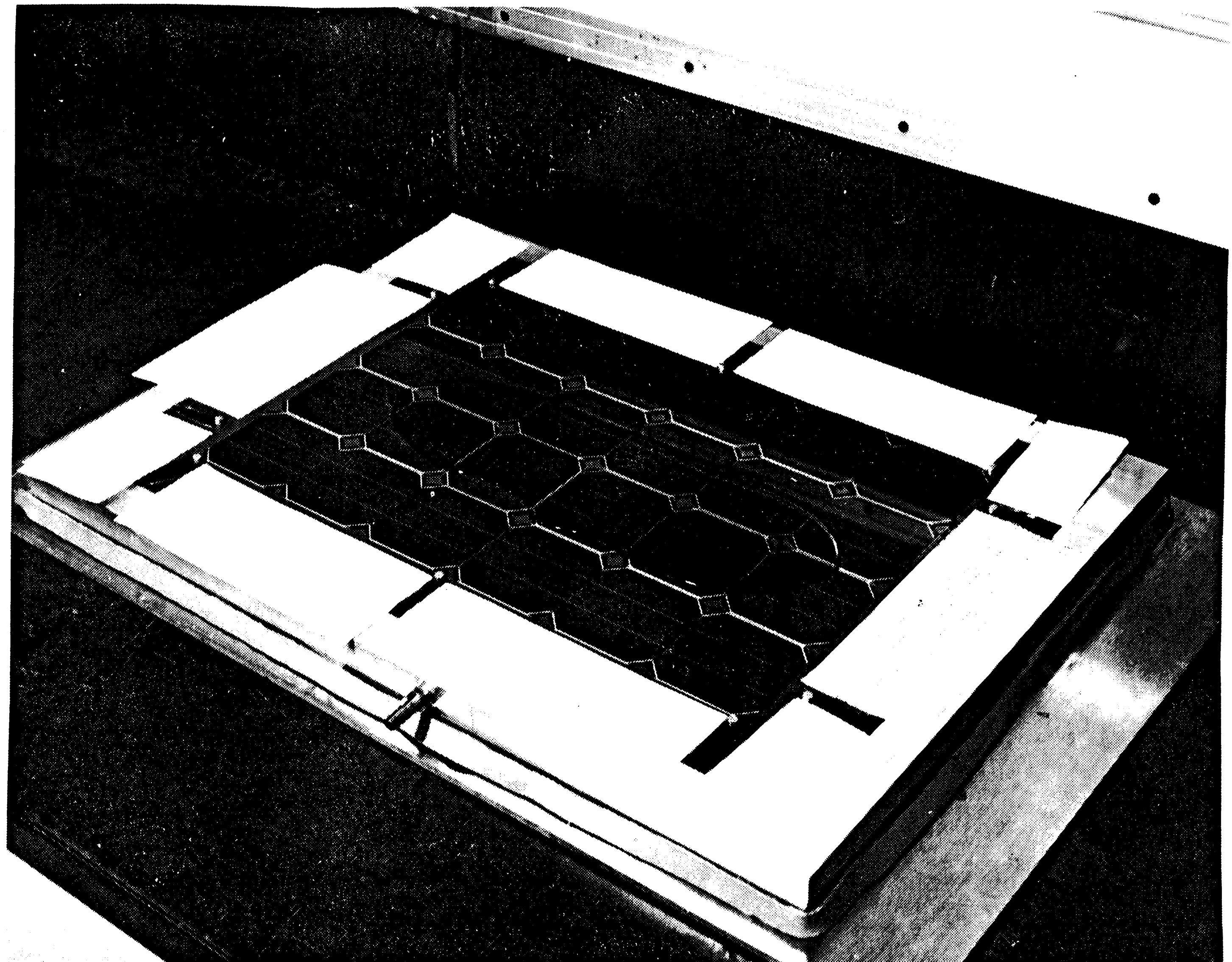
SOLAR CELLS FACE UP IN BONDING TOOL



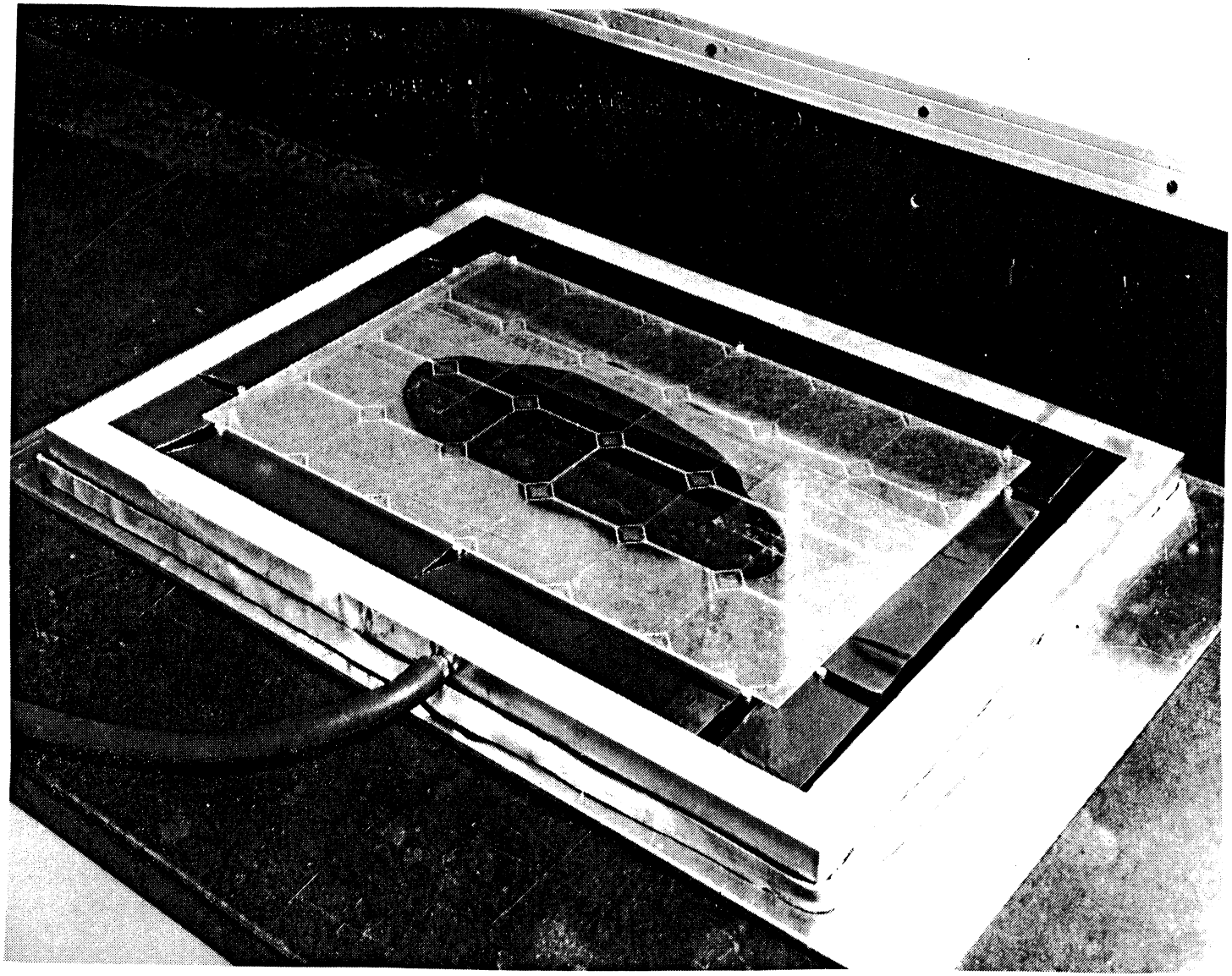
APPLY DC 93-500 ADHESIVE TO SOLAR CELLS



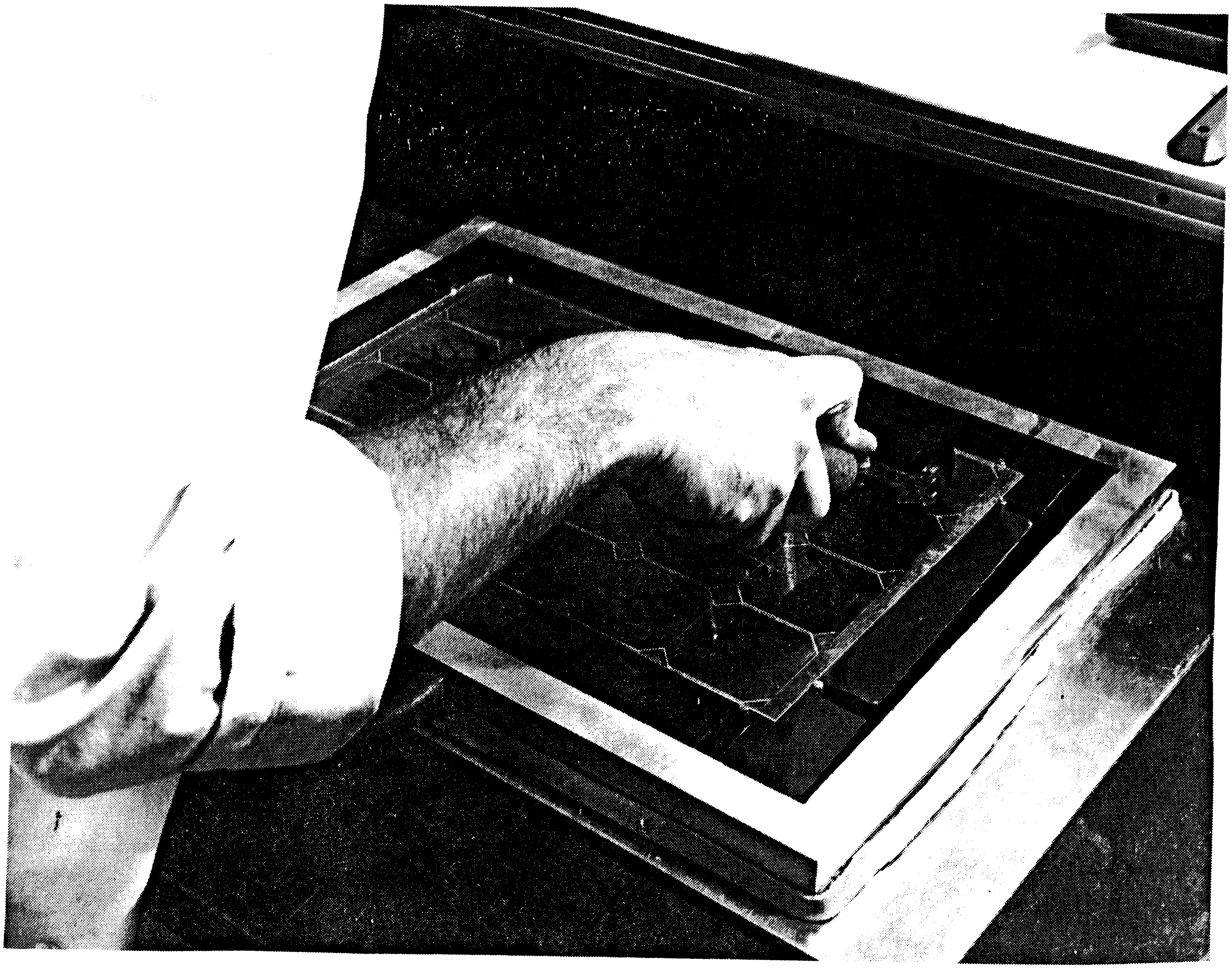
INITIAL APPLICATION OF DC 93-500 ADHESIVE



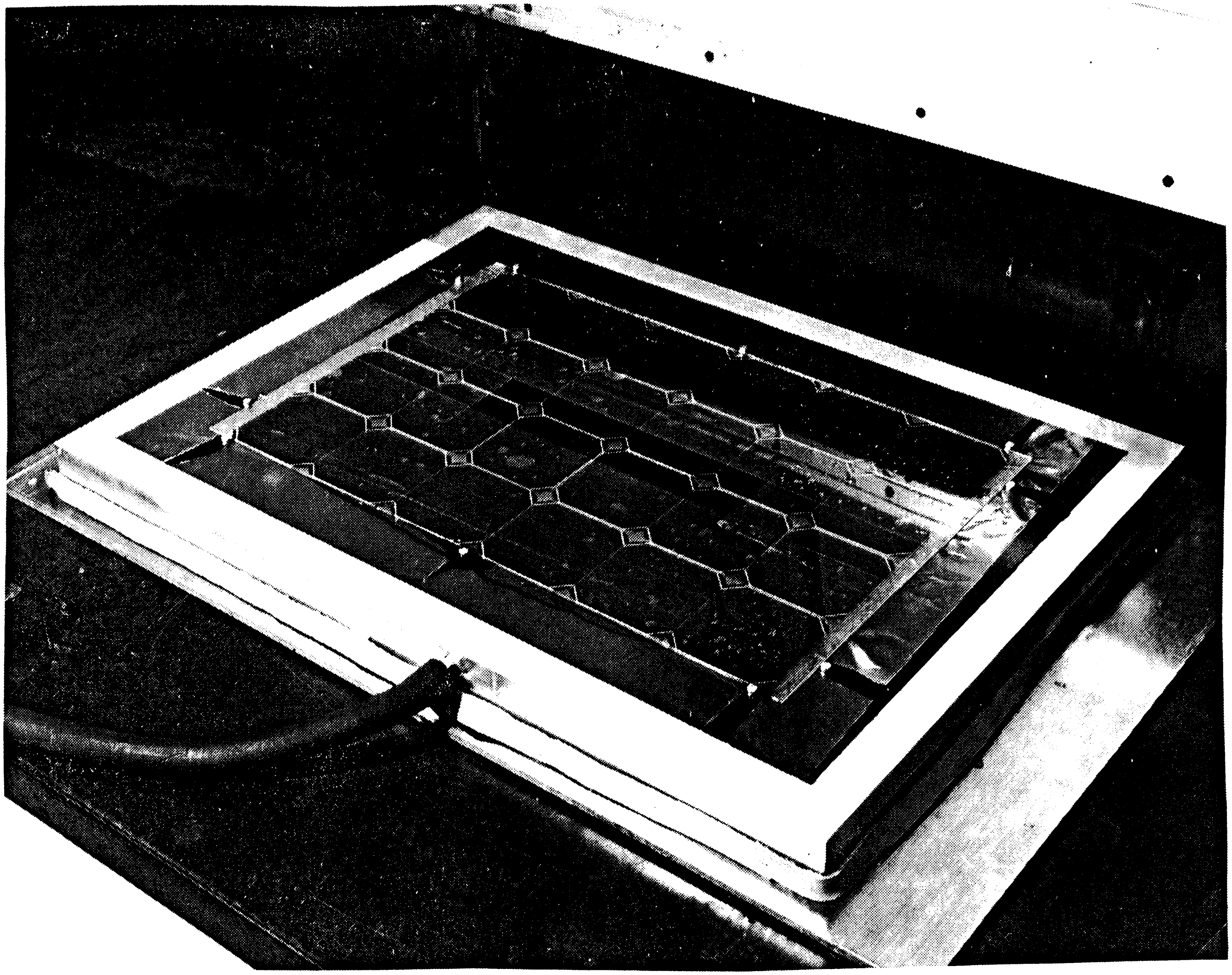
SUPERSTRATE GLASS WITH PRE CURED SCRIM CLOTH POSITIONED OVER SOLAR CELLS



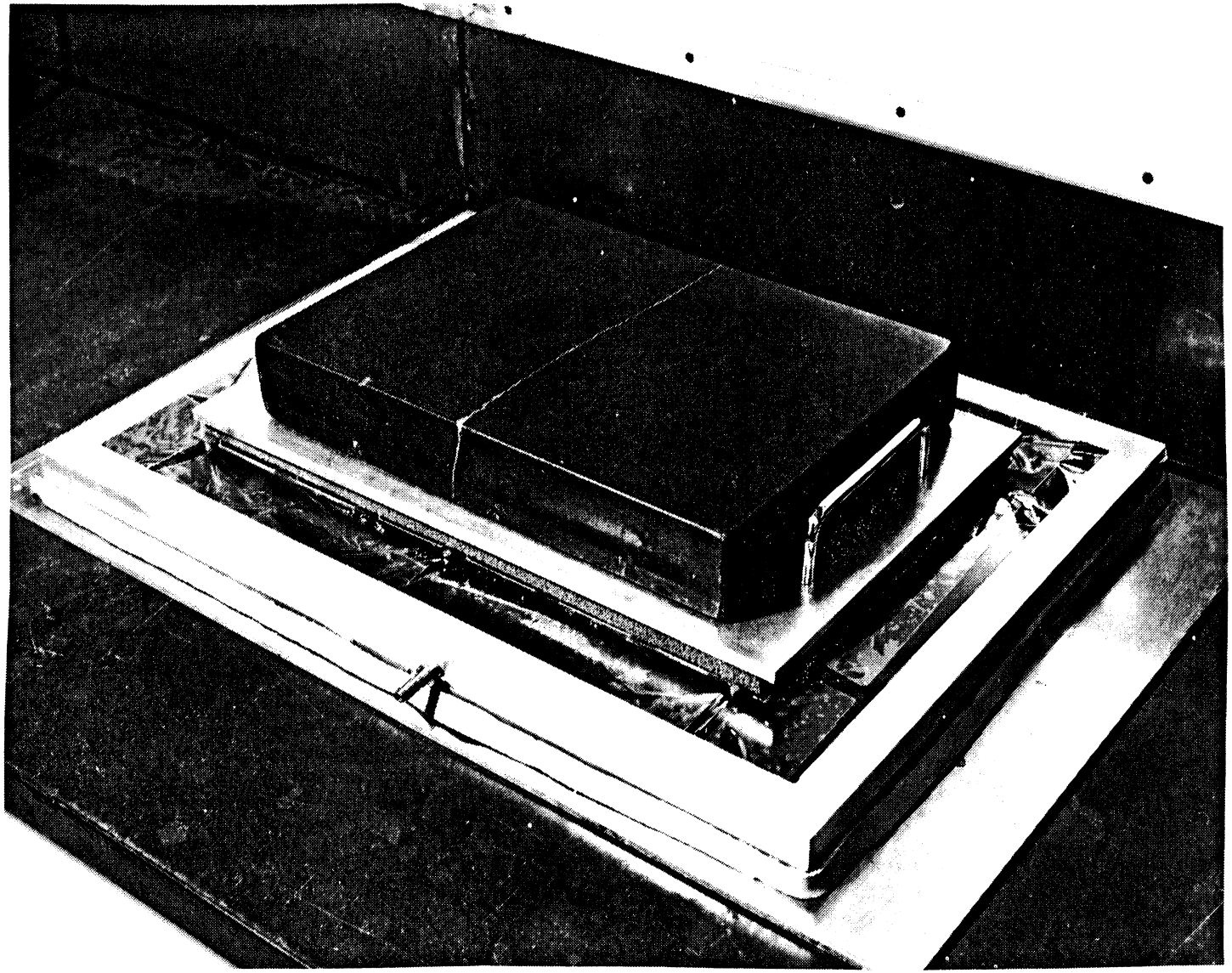
DISTRIBUTE ADHESIVE USING ROLLER



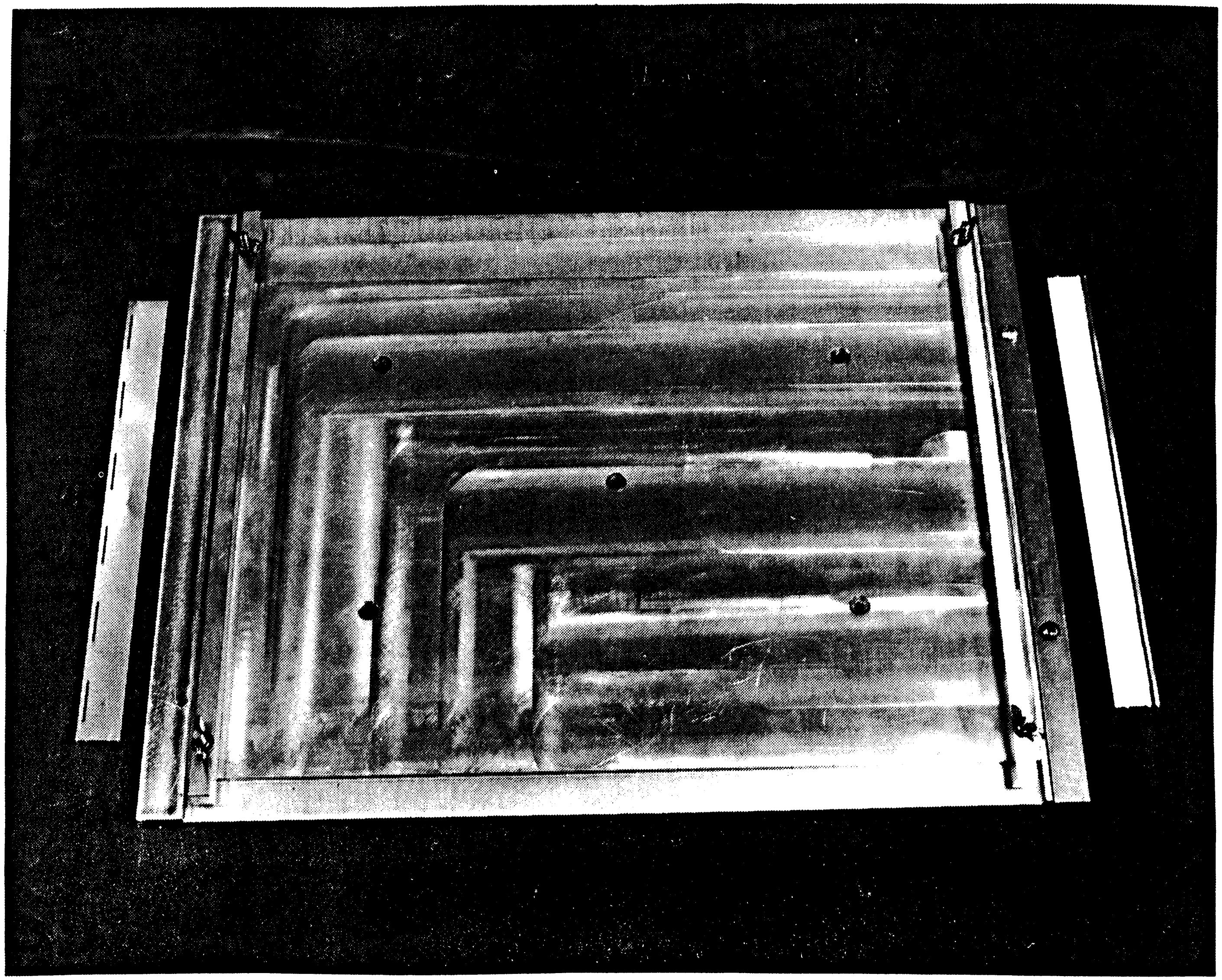
SUPERSTRATE ASSEMBLY WITH ADHESIVE EVENLY DISTRIBUTED



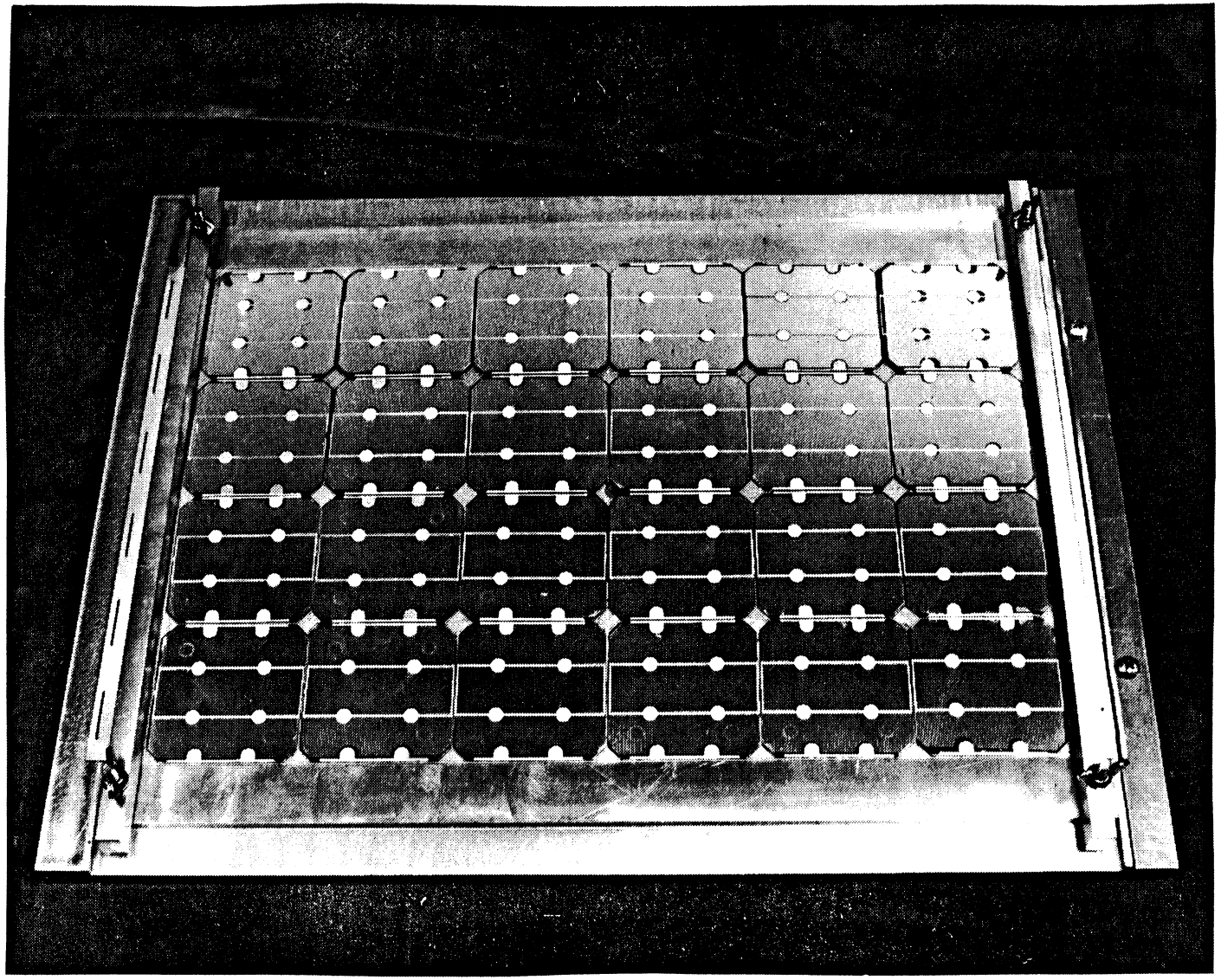
WEIGHT PLACED ON SUPERSTRATE ASSEMBLY BEFORE OVEN CURE



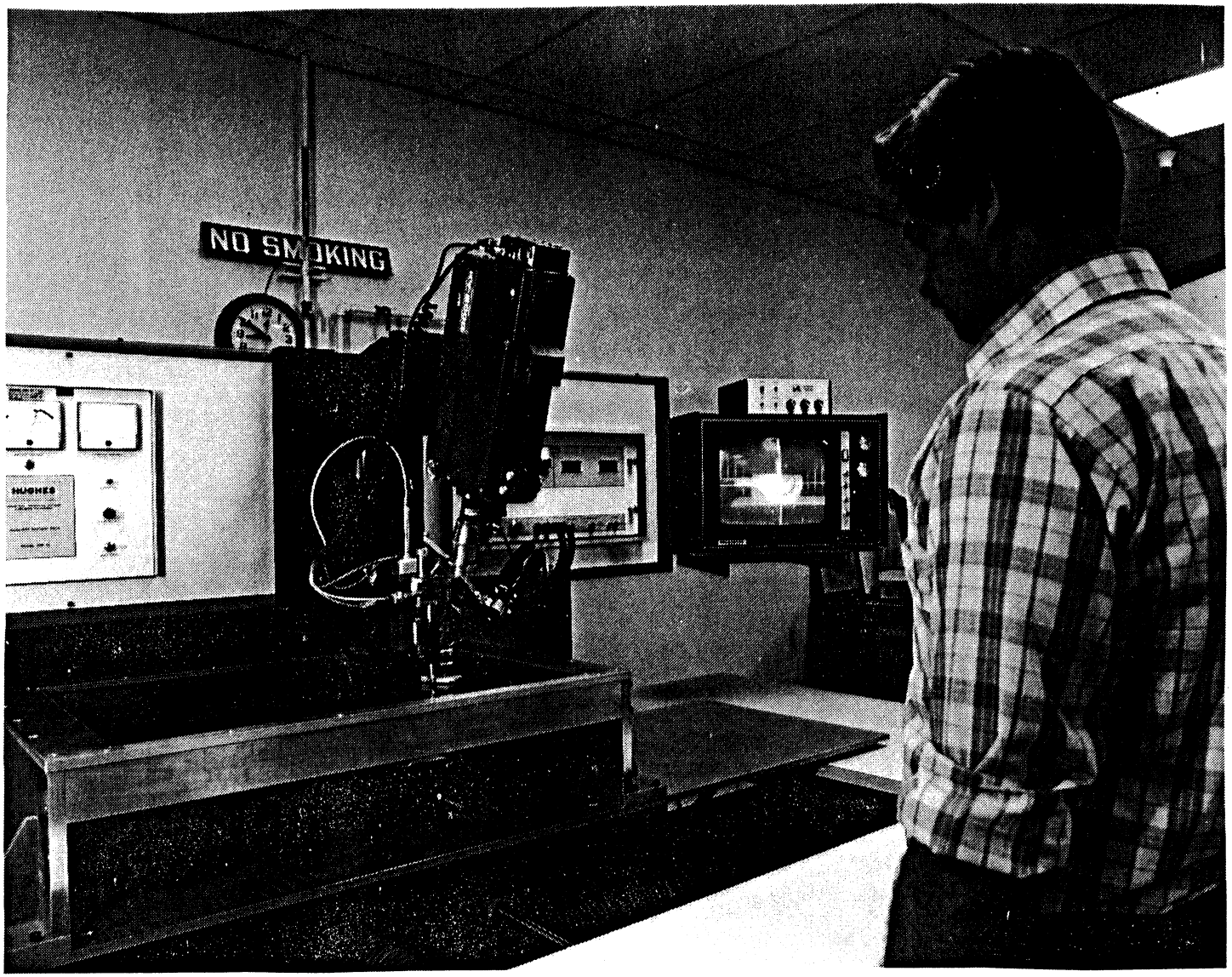
HINGE BONDING TOOL



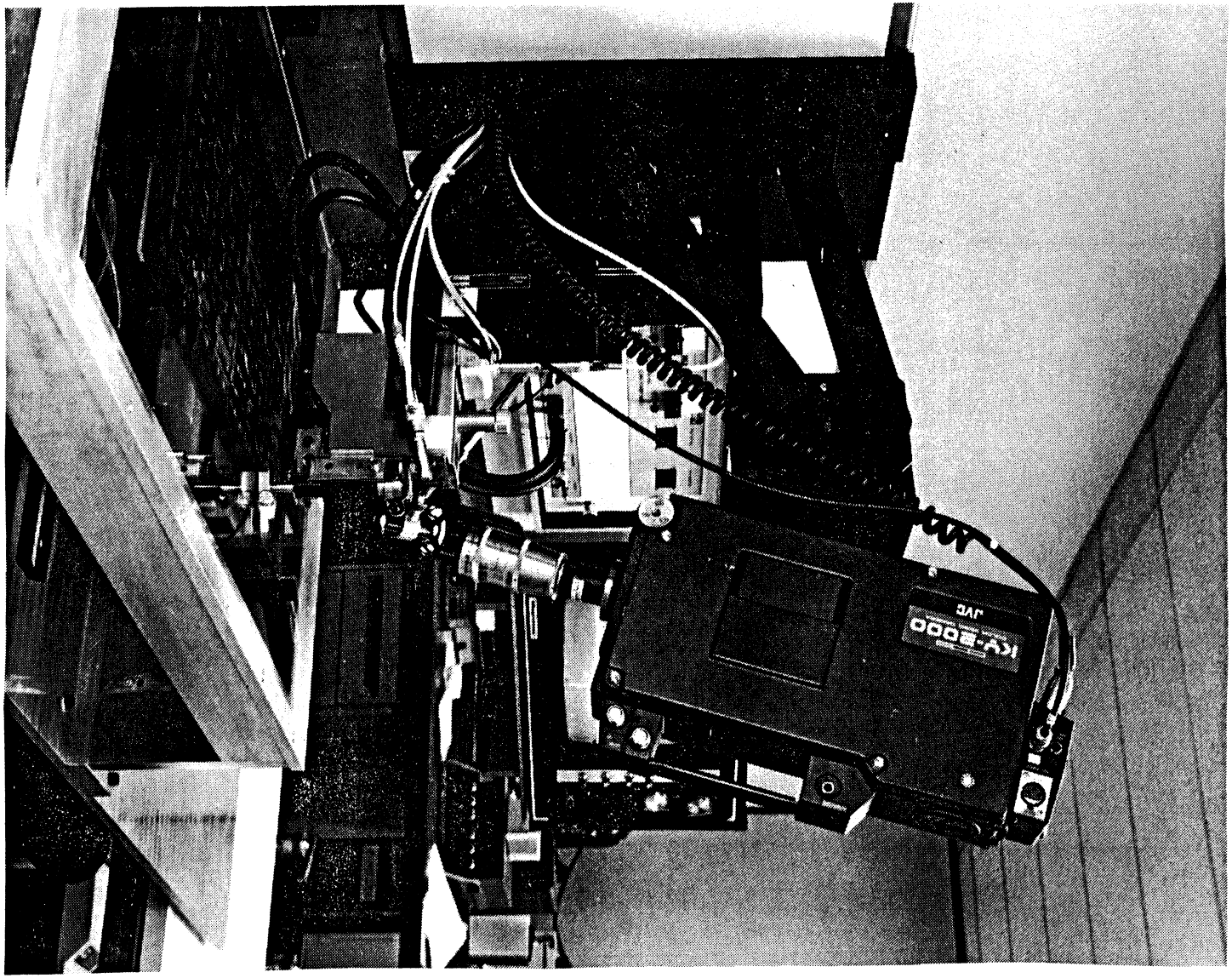
SUPERSTRATE ASSEMBLY POSITIONED IN BONDING TOOL



WELDER SET UP FOR WELDING SUPERSTRATE ASSEMBLY



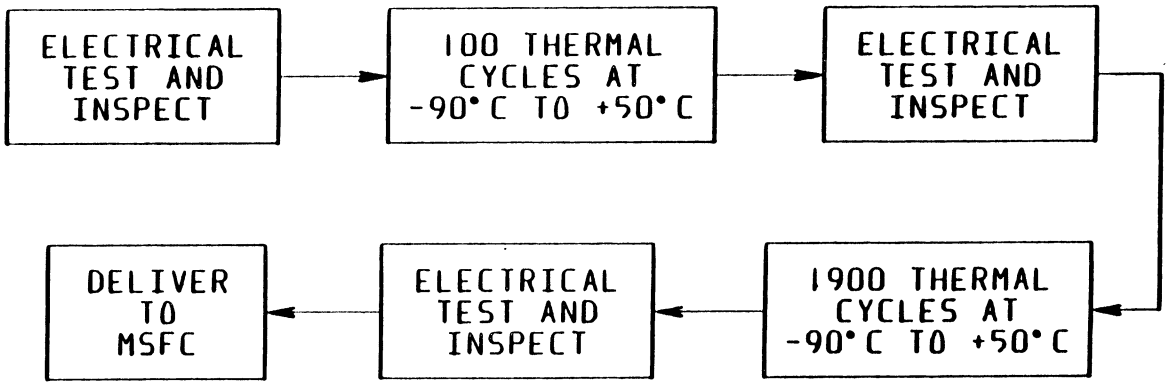
WELDING OF COPPER/KAPTON INTERCONNECT TO SUPERSTRATE ASSEMBLY



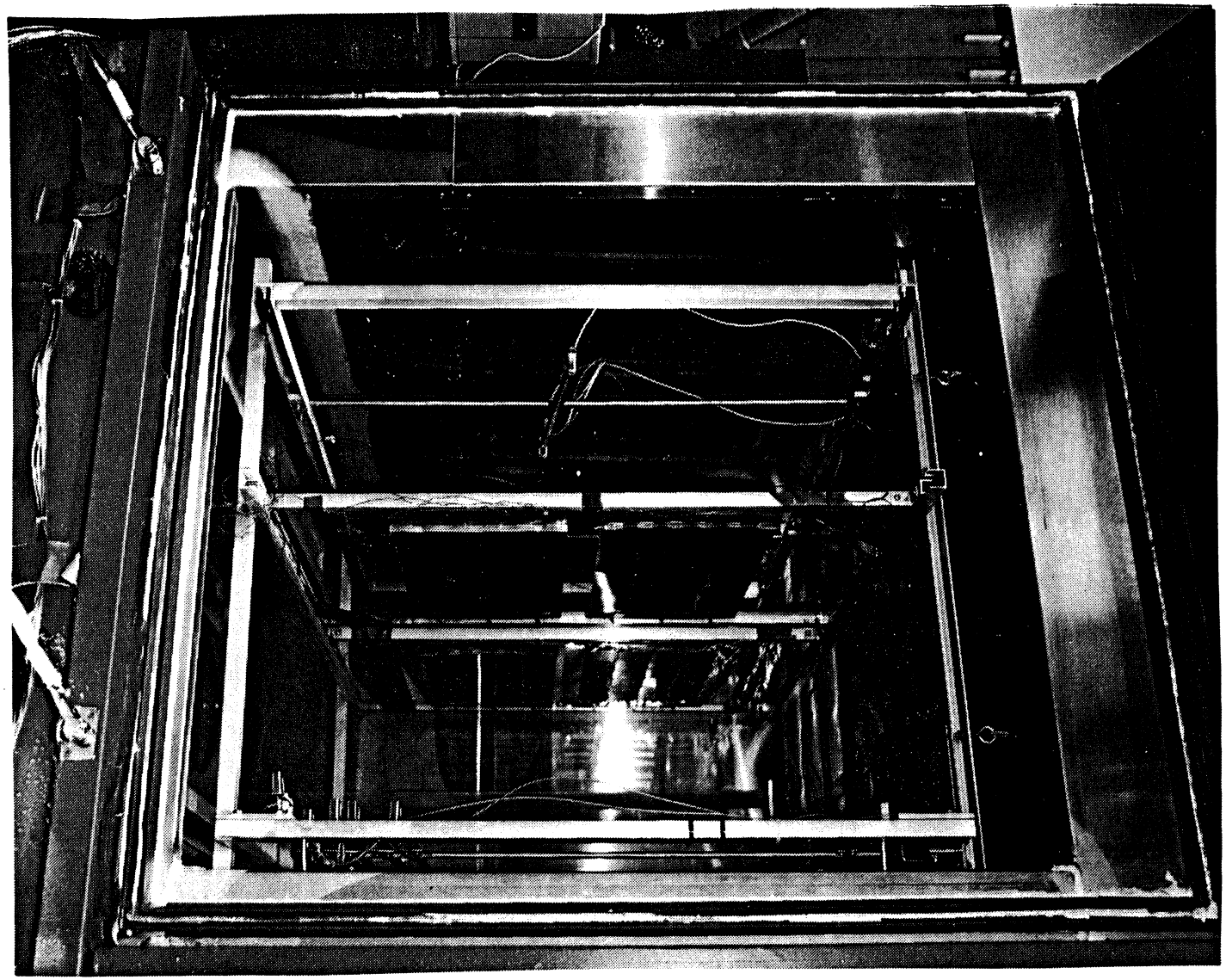
MODULE FABRICATION BREAKDOWN

ITEM	USE	NUMBER OF 24-CELL MODULES (SUPERSTRATE)	(CONVENTIONAL)
1 PANEL SEGMENT (GOOD ELECTRICAL)	THERMAL CYCLE AT MSFC	5	0
4 MODULES (GOOD ELECTRICAL)	THERMAL CYCLE AT LMSC	3	1
3 MODULES (GOOD ELECTRICAL)	THERMAL BALANCE AT BOEING	2	1
	TOTAL 24-CELL MODULES:	10	2

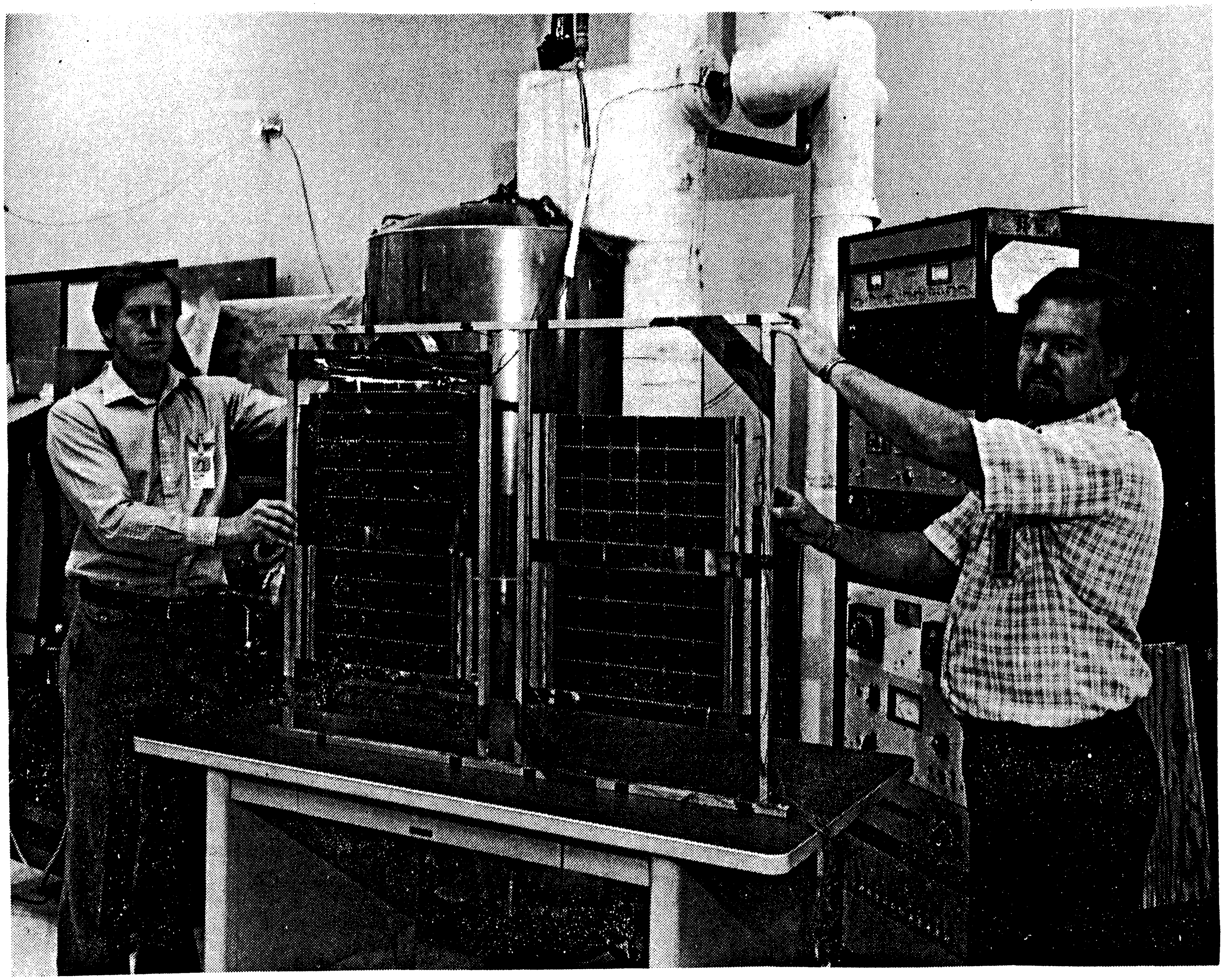
MODULE THERMAL CYCLE TEST SEQUENCE



THERMAL CYCLE TEST SETUP - FRONT SIDE



THERMAL CYCLE SAMPLES - FRONT SIDE



THERMAL BALANCE TESTING OBJECTIVES

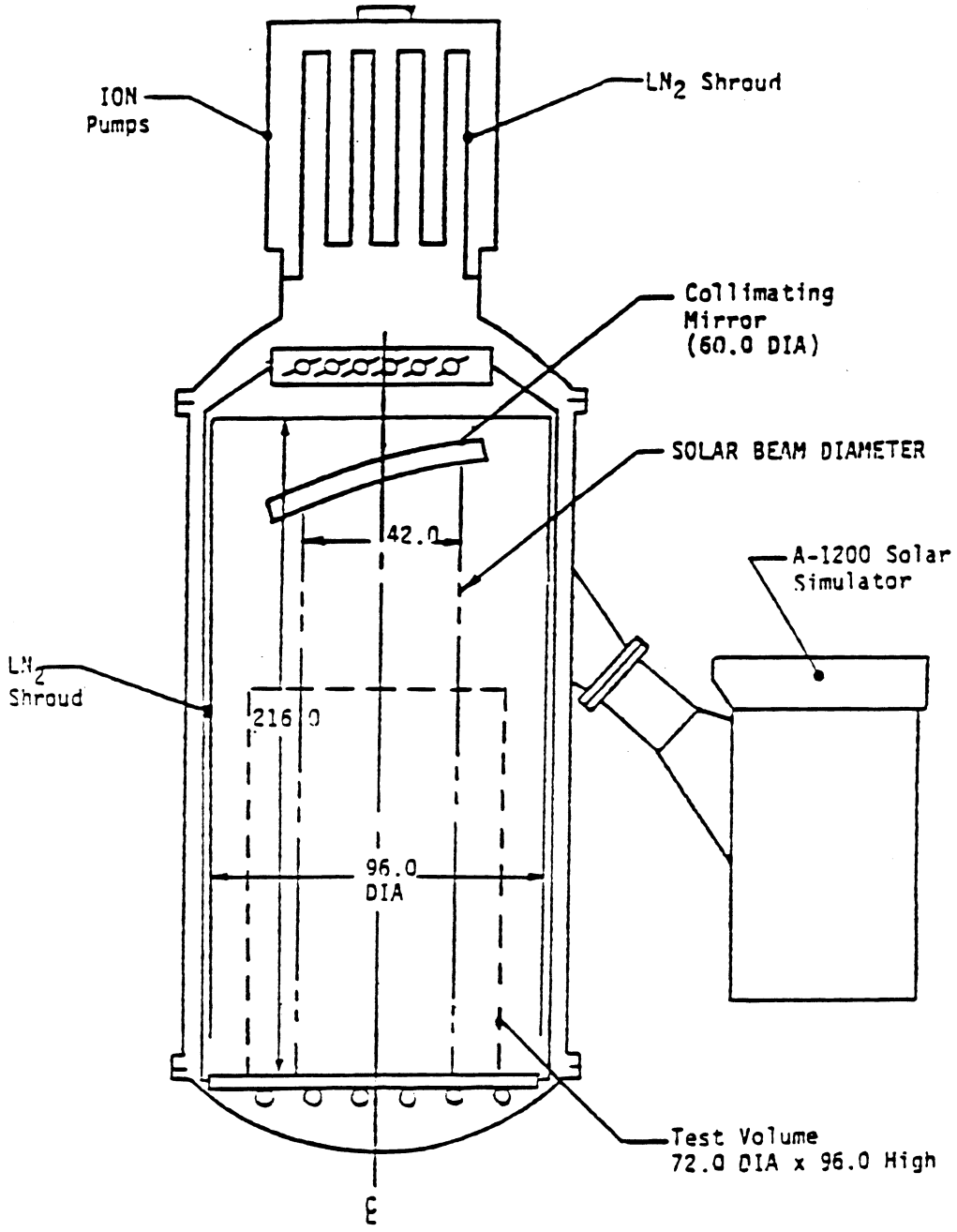
- VERIFY PREDICTED PERFORMANCE OF IR TRANSPARENT SOLAR ARRAY MODULES IN A LOW EARTH ORBIT

- DEMONSTRATE IMPROVED THERMAL PERFORMANCE OF IR TRANSPARENT MODULES OVER CONVENTIONAL MODULES

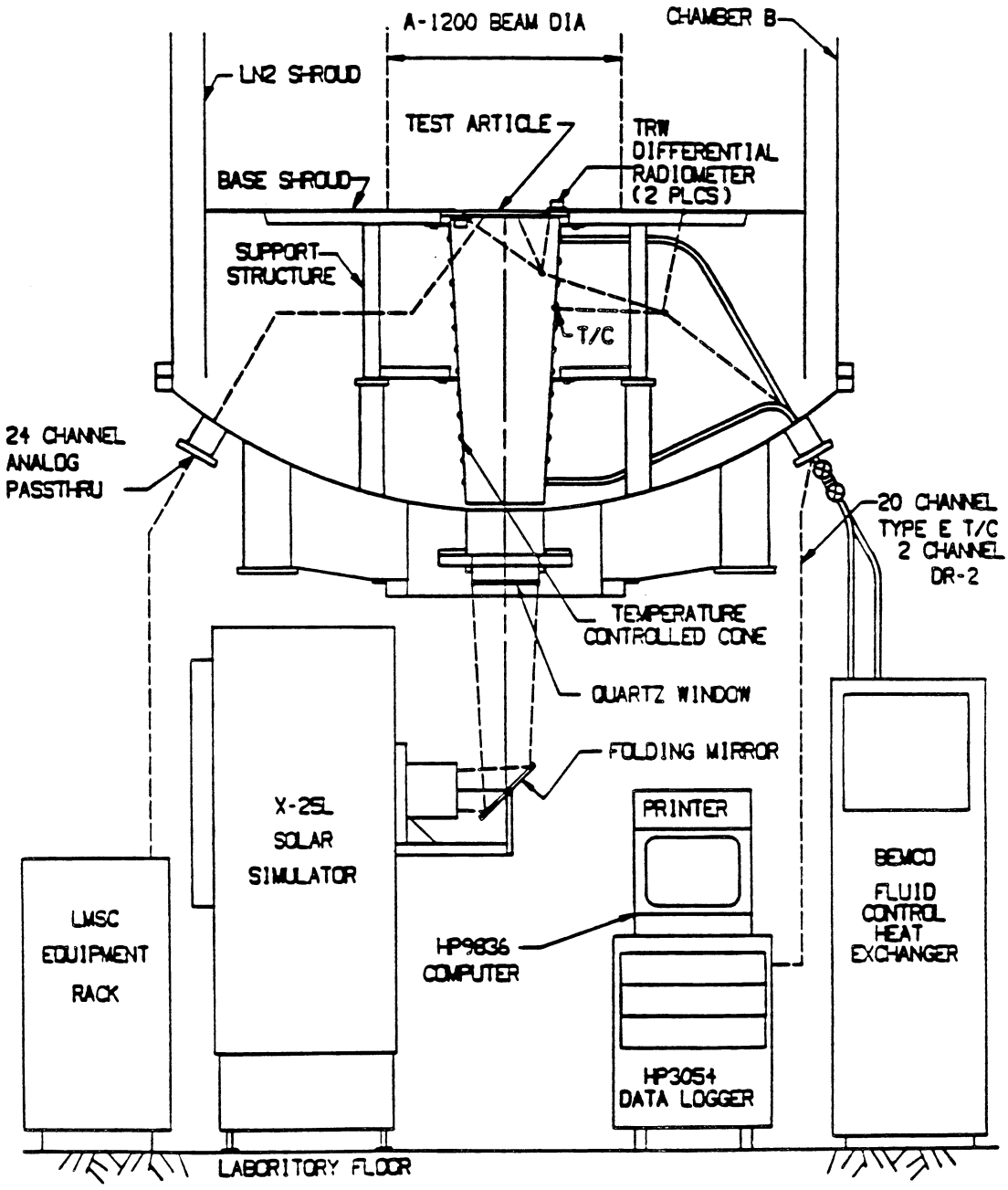
BOEING SPACE CHAMBER B

- THERMAL VACCUUM CHAMBER EQUIPPED WITH SOLAR AND ALBEDO SIMULATING LAMPS
  - A1200 SOLAR SIMULATOR
  - X25L ALBEDO SIMULATOR
  - FLUXES UNIFORM ACROSS TEST MODULES ($\pm$ 5%)
  - COLLIMATION ANGLE < 2 DEGREES
- PRESSURE < 10^{-5} TORR
- - 300 F LN_2 COLDWALL
- TEMPERATURE CONTROLLED CONE SIMULATES EARTH IR

SPACE CHAMBER B



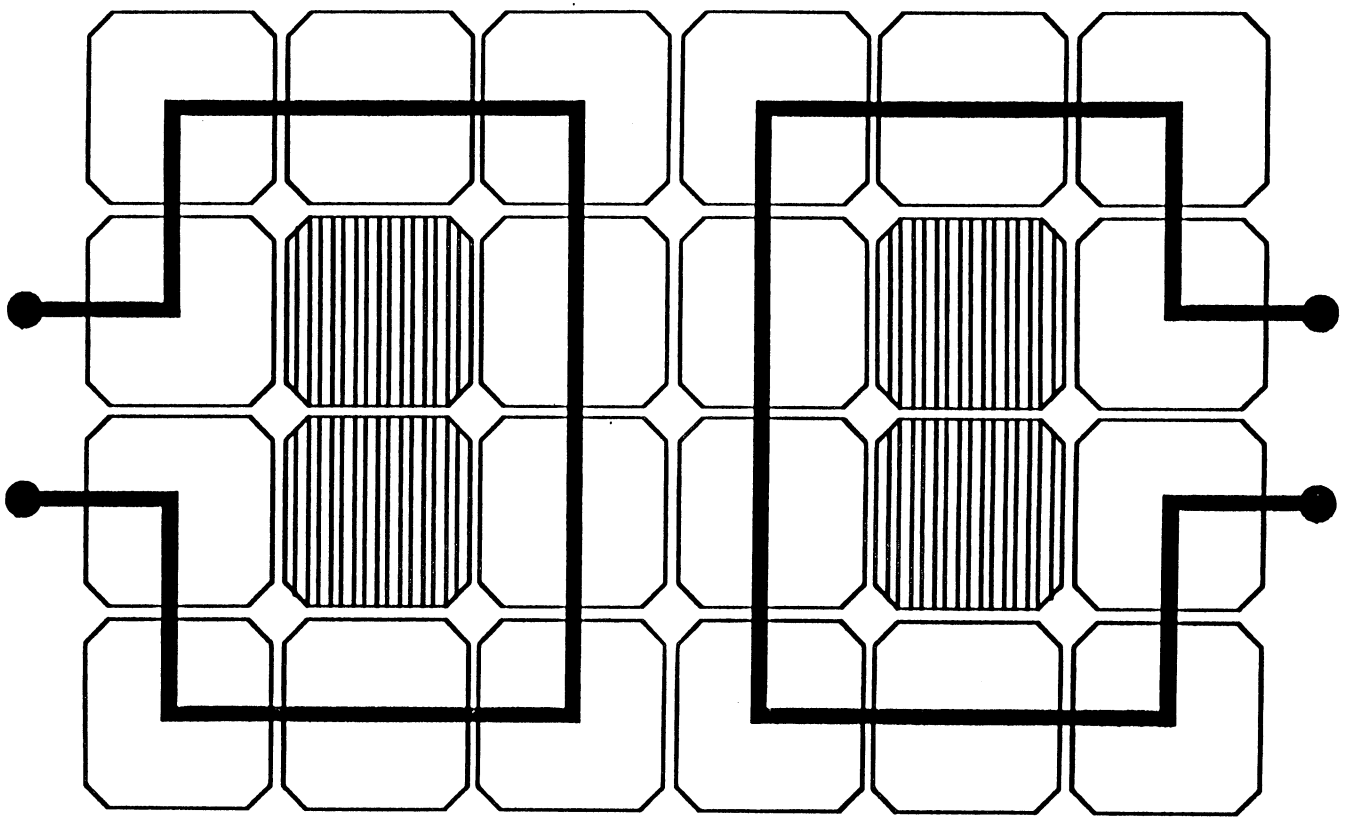
TEST SETUP


A-1200 BEAM DIA
CHAMBER B
LN2 SHROUD
TEST ARTICLE
TRW DIFFERENTIAL RADIOMETER (2 PLCS)
BASE SHROUD
SUPPORT STRUCTURE
T/C
24 CHANNEL ANALOG PASSTHRU
20 CHANNEL TYPE E T/C 2 CHANNEL DR-2
TEMPERATURE CONTROLLED CONE
QUARTZ WINDOW
FOLDING MIRROR
X-25L SOLAR SIMULATOR
PRINTER
LMSC EQUIPMENT RACK
HP9836 COMPUTER
BEMCO FLUID CONTROL HEAT EXCHANGER
HP3054 DATA LOGGER
LABORITORY FLOOR

SOLAR ARRAY TEST MODULES

- 24 CELLS ARRANGED IN A 6X4 MATRIX
- 3 MODULES FABRICATED AND TESTED
- CONVENTIONAL OPAQUE MODULE
  - BACK SURFACE REFLECTING CELLS
  - FULL KAPTON SUBSTRATE
- IR TRANSPARENT MODULE WITH FULL KAPTON SUBSTRATE
  - GRIDDED BACK SURFACE CELLS
  - SELECTIVELY TRANSMITS WAVELENGTHS BEYOND 1 MICRON
- IR TRANSPARENT MODULE WITH CUTAWAY SUBSTRATE
  - 60% OF KAPTON SUBSTRATE CUTAWAY
- NO BONDING BETWEEN CELL AND SUBSTRATE

SOLAR CELL ELECTRICAL CIRCUITS



FOUR CELLS INDIVIDUALLY CONTROLLED

THERMAL BALANCE TESTING

- FIVE TEST CONDITIONS FOR EACH OF THE THREE TEST MODULES
  - 0.97 SOLAR
  - 1.03 SOLAR
  - 1.00 SOLAR
  - 1.00 SOLAR, 0.30 ALBEDO
  - 1.00 SOLAR, 0.40 ALBEDO

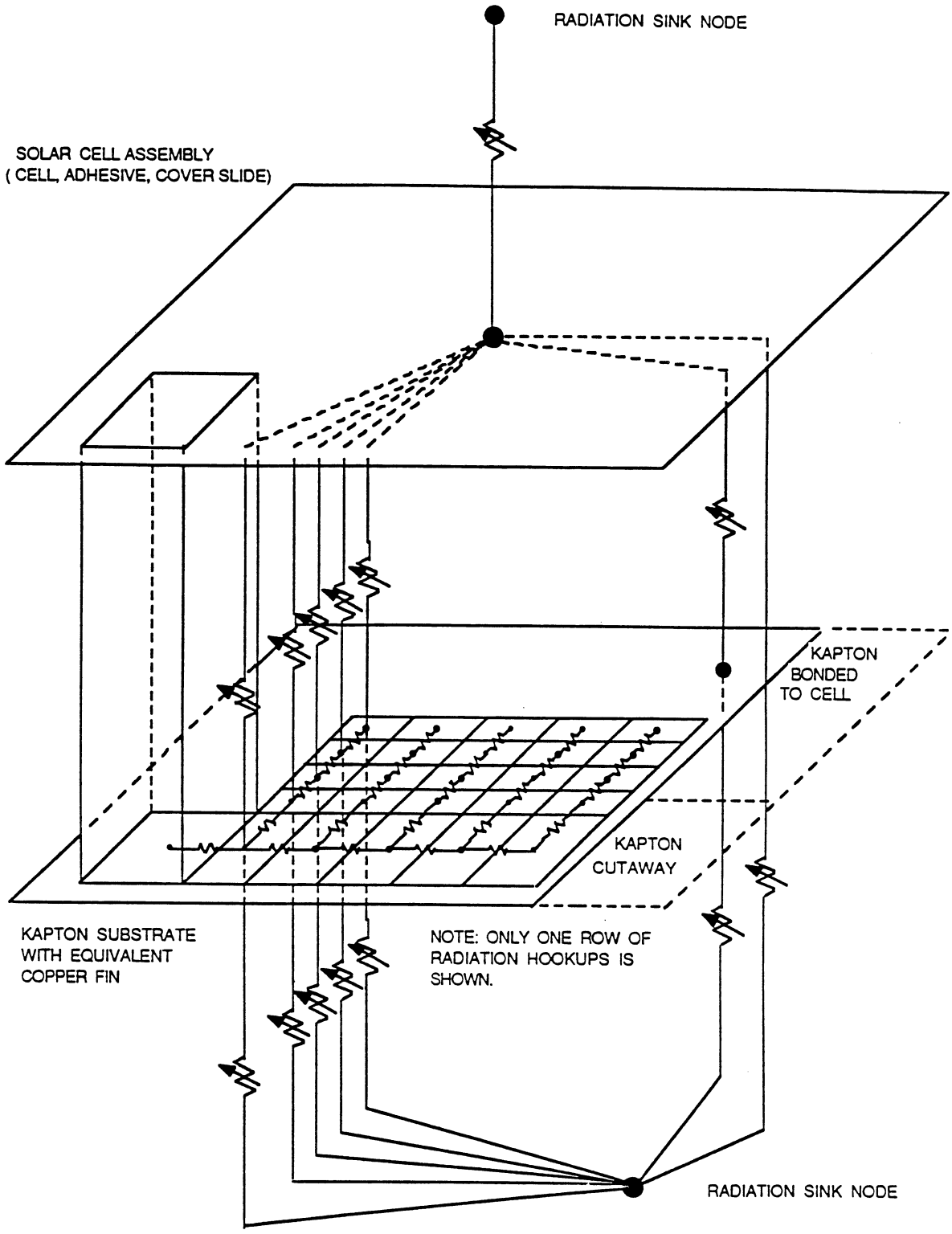
- SEVERAL ELECTRICAL POWER SETTINGS FOR EACH TEST CONDITION
  - OPEN CIRCUIT
  - RESISTANCE SETTINGS TO BOUND MAXIMUM POWER POINT

- TEMPERATURES AND CELL POWER DATA RECORDED AT 1 MINUTE INTERVALS

THERMAL MODELLING

- ONLY ONE CELL MODELLED
  - SOLAR AND ALBEDO FLUXES UNIFORM OVER TEST MODULE
  - HIGH THERMAL RESISTANCE BETWEEN CELLS
  - SIMILIAR VIEW FACTORS TO CHAMBER SURFACES
- NEGLECT CONDUCTION LOSSES FROM TEST MODULES
- RADIATION NETWORK CREATED BY COMPUTER MODELLING OF CHAMBER SURFACES
- ELECTRICAL POWER SUBTRACTED FROM TOTAL ABSORBED HEAT
- THERMAL SURFACE PROPERTIES OF ARRAY MATERIALS INTEGRATED WITH RESPECT TO SOLAR AND ALBEDO SIMULATORS' SPECTRAL DISTRIBUTIONS OF ENERGY
- ABSORBED HEAT LOAD INCLUDES SECONDARY TERMS DUE TO REFLECTION AND TRANSMISSION OF ENERGY WITHIN MODULE

CELL THERMAL MODEL



THERMAL SURFACE PROPERTIES

MATERIAL	SUN			A1200 SOLAR SIMULATOR			X25L ALBEDO SIMULATOR		
	α	ρ	τ	α	ρ	τ	α	ρ	τ
OPAQUE CELL ASSEMBLY FRONTFACE (CELL, ADHESIVE, COVERSLIDE)	0.68	0.32	0.0	0.72	0.28	0.0	–	–	–
OPAQUE CELL ASSEMBLY BACKFACE (CELL, ADHESIVE, COVERSLIDE)	0.08	0.92	0.0	–	–	–	0.08	0.92	0.0
TRANSPARENT CELL ASSEMBLY FRONTFACE (CELL, ADHESIVE, SUPERSTRATE)	0.62	0.21	0.17	0.69	0.14	0.17	–	–	–
TRANSPARENT CELL ASSEMBLY BACKFACE (CELL, ADHESIVE, SUPERSTRATE)	0.62	0.21	0.17	–	–	–	0.57	0.30	0.13

SPECTRAL ENERGY DISTRIBUTION MEASUREMENT FOR A-1200

	BAND NO.	BANDWIDTH (MICRONS)	MATCHED DATA	NORMALIZED MATCHED DATA TO ONE SOLAR CONSTANT (w/m**2)	ENG STANDARD	% DEVIATION
	1	0.25-0.35	4.3	19.9	58.5	-65.9
	2	0.35-0.40	13.2	61.2	56.9	7.5
100% ABSORPTION	3	0.40-0.45	17.9	83.0	86.8	-4.4
	4	0.45-0.50	21.8	101.0	100.9	0.1
	5	0.50-0.60	44.7	207.2	177.0	17.1
	6	0.60-0.70	38.0	176.1	151.5	16.3
	7	0.70-0.80	29.0	134.4	123.7	8.7
	8	0.80-0.90	21.5	99.7	99.3	0.4
	9	0.90-1.00	16.4	76.0	82.9	-8.3
	10	1.00-1.20	25.0	115.9	120.6	-3.9
	11	1.20-1.50	22.4	103.8	111.4	-6.8
IR	12	1.50-1.80	14.5	67.2	67.0	0.3
	13	1.80-2.20	8.4	38.9	43.8	-11.1
	14	2.20-2.50	3.4	15.8	19.8	-20.4
	TOTAL		280.5	1300.1	1300.1	

SPECTRAL ENERGY DISTRIBUTION MEASUREMENT FOR X-25

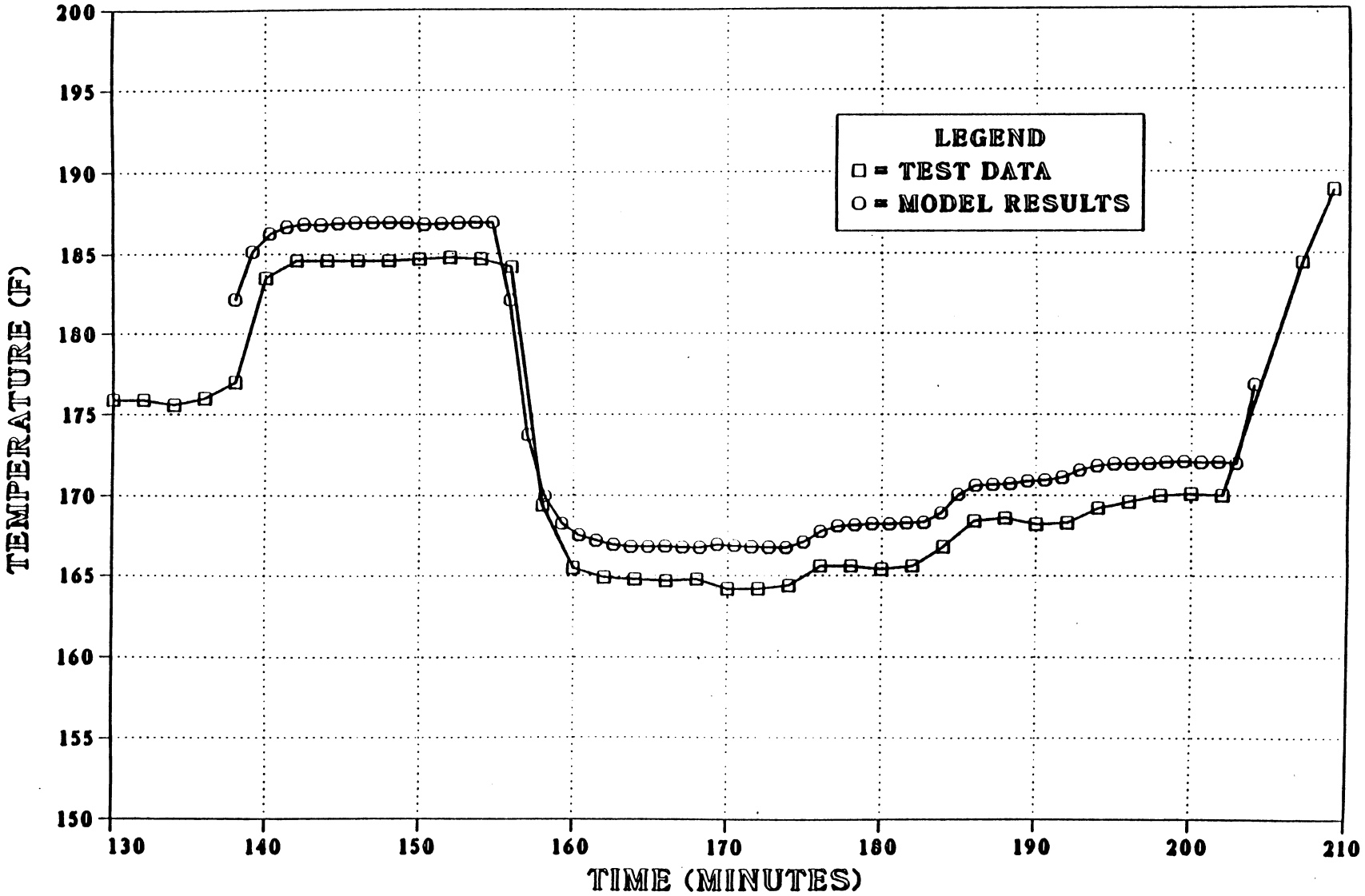
	BAND NO.	BANDWIDTH (MICRONS)	MATCHED DATA	NORMALIZED MATCHED DATA TO ONE SOLAR CONSTANT (w/m**2)	ENG STANDARD	% DEVIATION
	1	0.25-0.35	3.4	17.9	58.5	-69.4
	2	0.35-0.40	9.1	47.9	56.9	-15.9
100% ABSORPTION	3	0.40-0.45	13.6	71.5	86.8	-17.6
	4	0.45-0.50	15.3	80.5	100.9	-20.3
	5	0.50-0.60	32.0	168.3	177.0	-4.9
	6	0.60-0.70	28.3	148.8	151.5	-1.8
	7	0.70-0.80	23.5	123.6	123.7	-0.1
	8	0.80-0.90	20.7	108.9	99.3	9.6
	9	0.90-1.00	18.2	95.7	82.9	15.5
	10	1.00-1.20	27.0	142.0	120.6	17.7
	11	1.20-1.50	26.5	139.4	111.4	25.1
IR	12	1.50-1.80	16.2	85.2	67.0	27.2
	13	1.80-2.20	9.5	50.0	43.8	14.1
	14	2.20-2.50	3.9	20.5	19.8	3.6
	TOTAL		247.2	1300.1	1300.1	

OPAQUE CELL WITH FULL SUBSTRATE

JULY 23 TESTS

SOLAR=1.0, ALBEDO= 0.0

THERMOCOUPLE #3, POWER CIRCUIT #3



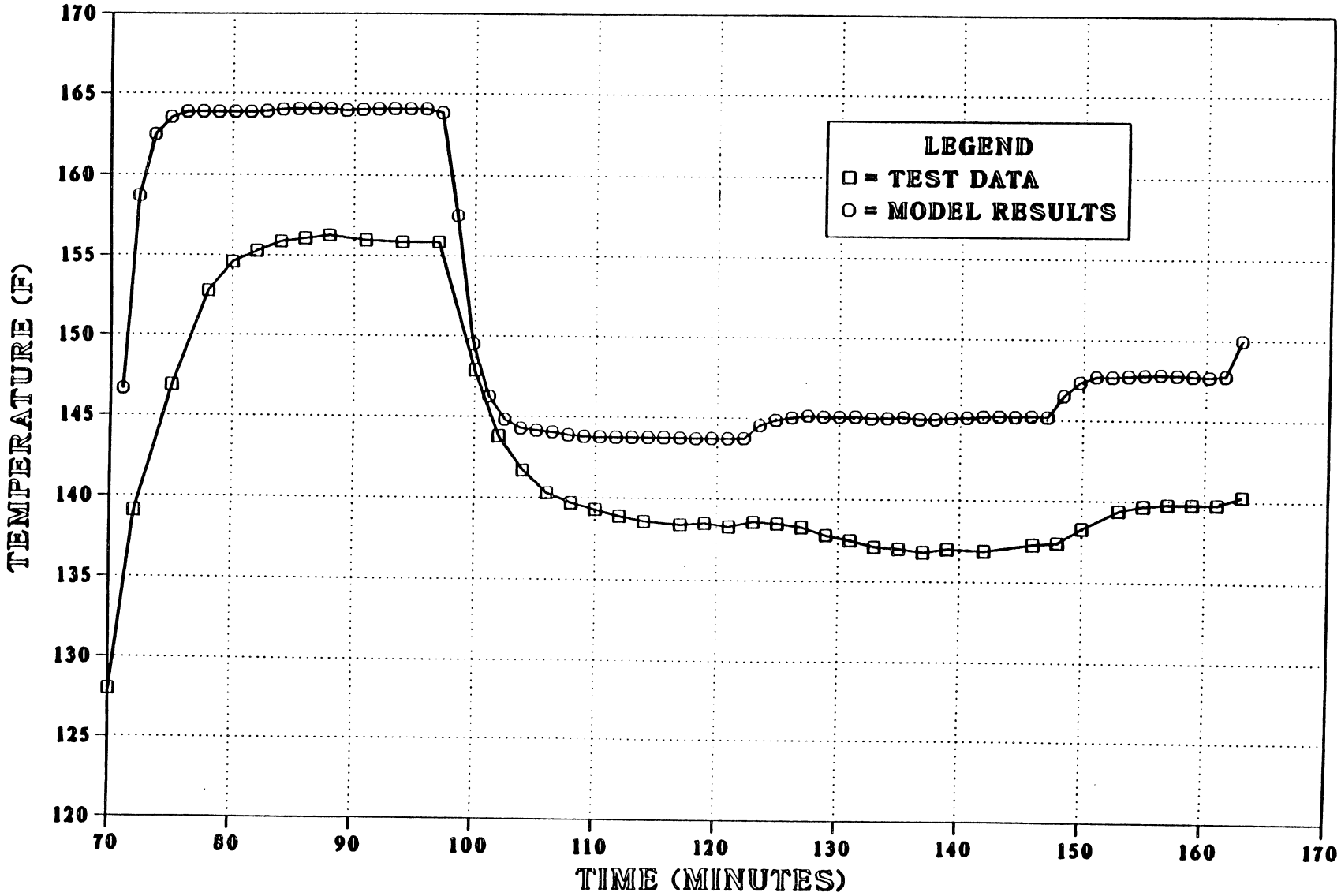
15-APR-87, *Thermodynamics*

TRANSPARENT CELL WITH FULL SUBSTRATE

JULY 25 TESTS

SOLAR=1.03, ALBEDO= 0.0

THERMOCOUPLE #4, POWER CIRCUIT #4



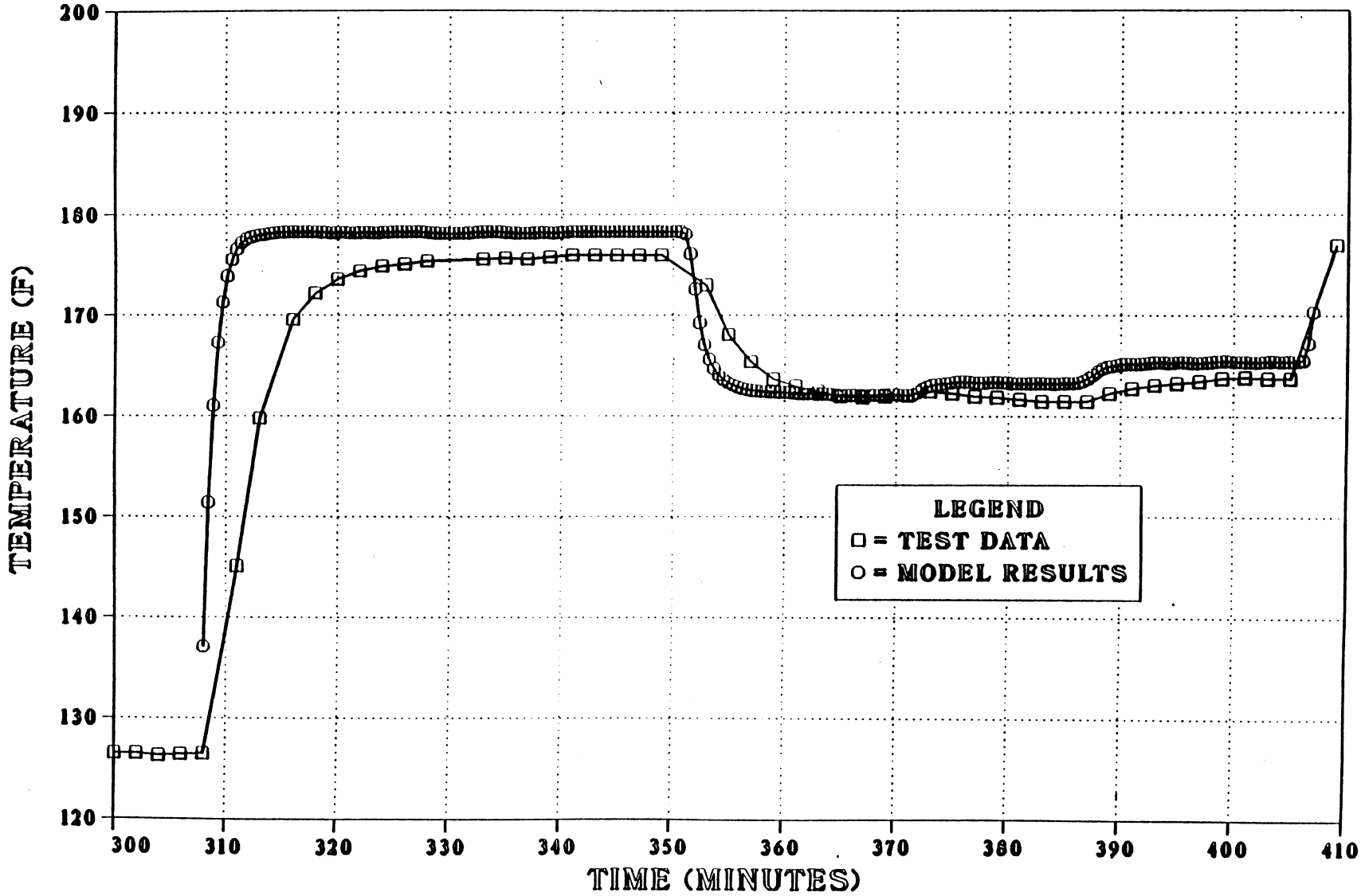
15-APR-87, *Thermodynamics*

TRANSPARENT CELL WITH CUTAWAY SUBSTRATE

JULY 24 TESTS

SOLAR=1.00, ALBEDO= 0.30

THERMOCOUPLE #3, POWER CIRCUIT #3



15-APR-87, *Thermodynamics*

CORRELATION BETWEEN MODEL RESULTS AND TEST DATA

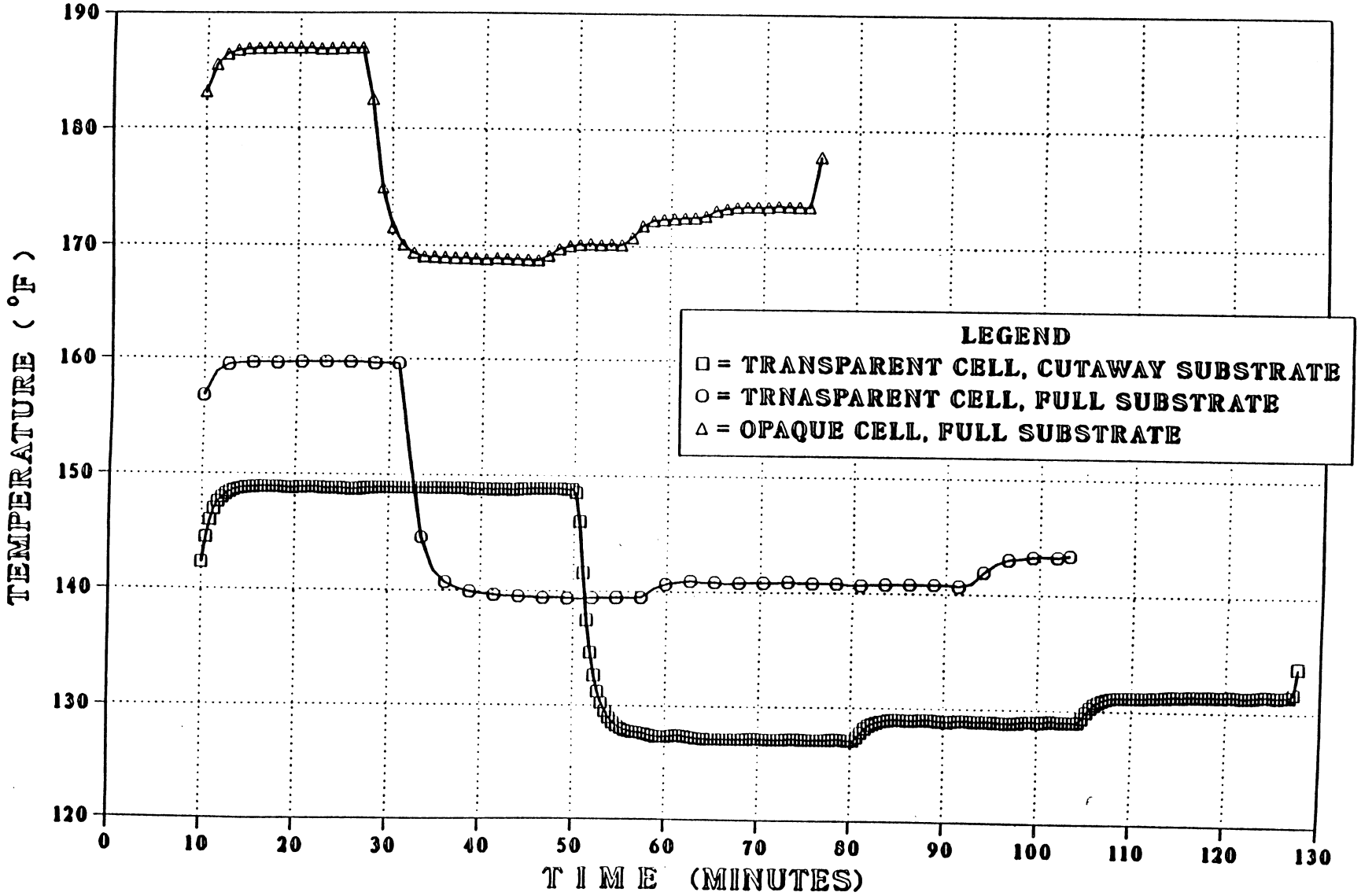
- OPAQUE TEST MODULE
  - MODEL RESULTS AND TEST DATA WITHIN 5 F IN 17 OF 20 CASES AT ALL STEADY STATE CONDITIONS
- TRANSPARENT TEST MODULE WITH FULL SUBSTRATE
  - MODEL RESULTS AND TEST DATA WITHIN 10 F IN 12 OF 15 CASES AT ALL STEADY STATE CONDITONS
  - MODEL RESULTS WARMER THAN TEST DATA
- TRANSPARENT TEST MODULE WITH CUTAWAY SUBSTRATE
  - MODEL RESULTS AND TEST DATA WITHIN 5 F IN ALL 20 CASES AT ALL STEADY STATE CONDITIONS
  - MODEL RESULTS PREDICT MORE RAPID TRANSIENT RESPONSE THAN TEST DATA SHOWS

PREDICTED SOLAR CELL TEST TEMPERATURES

FOR THREE ARRAY DESIGNS

SOLAR = 1.0, ALBEDO = 0.0

POWER CIRCUIT #2



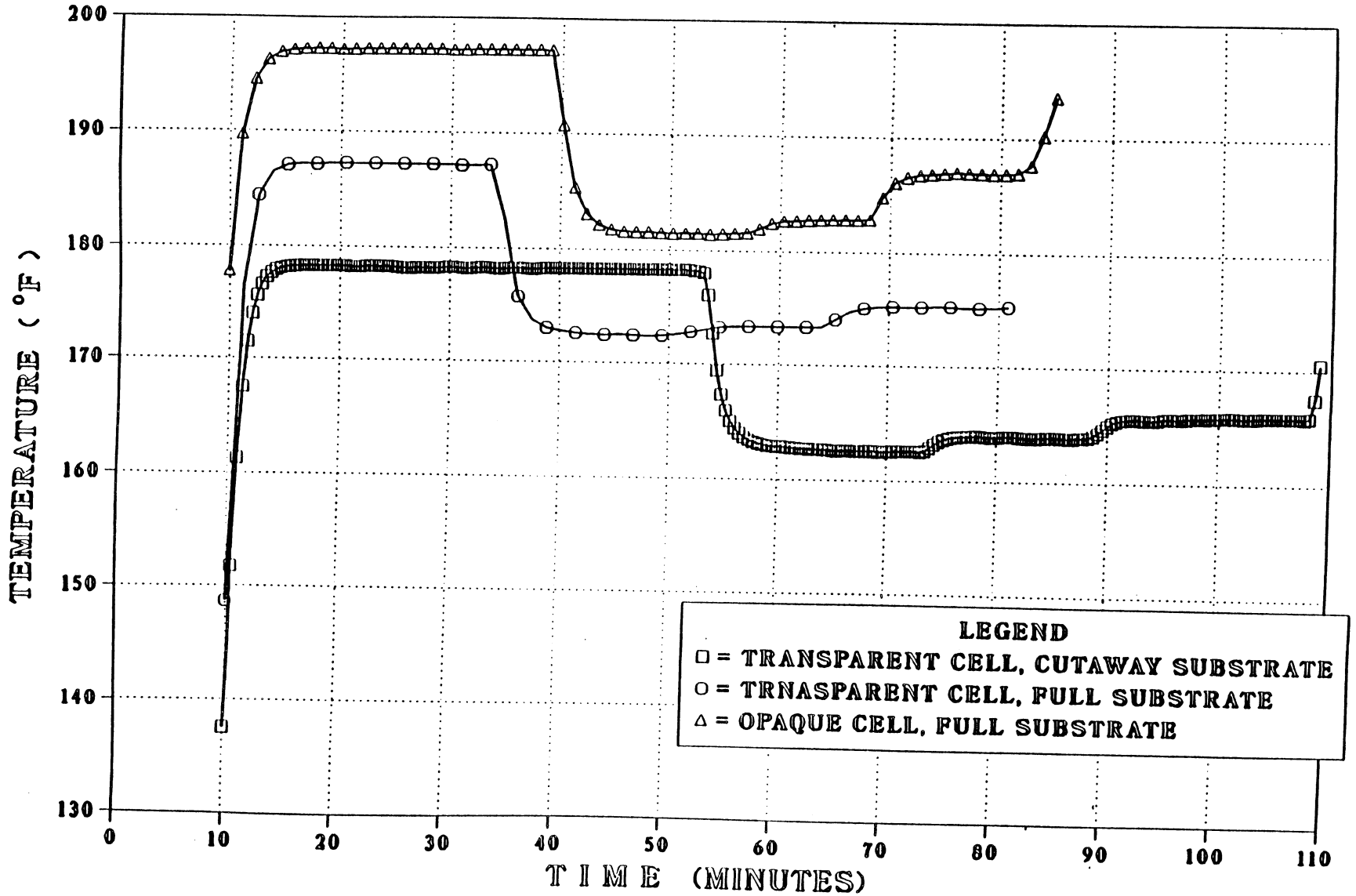
28-APR-87, *Thermodynamics*

PREDICTED SOLAR CELL TEST TEMPERATURES

FOR THREE ARRAY DESIGNS

SOLAR = 1.0, ALBEDO = 0.30

POWER CIRCUIT #2



28-APR-87, *Thermodynamics*

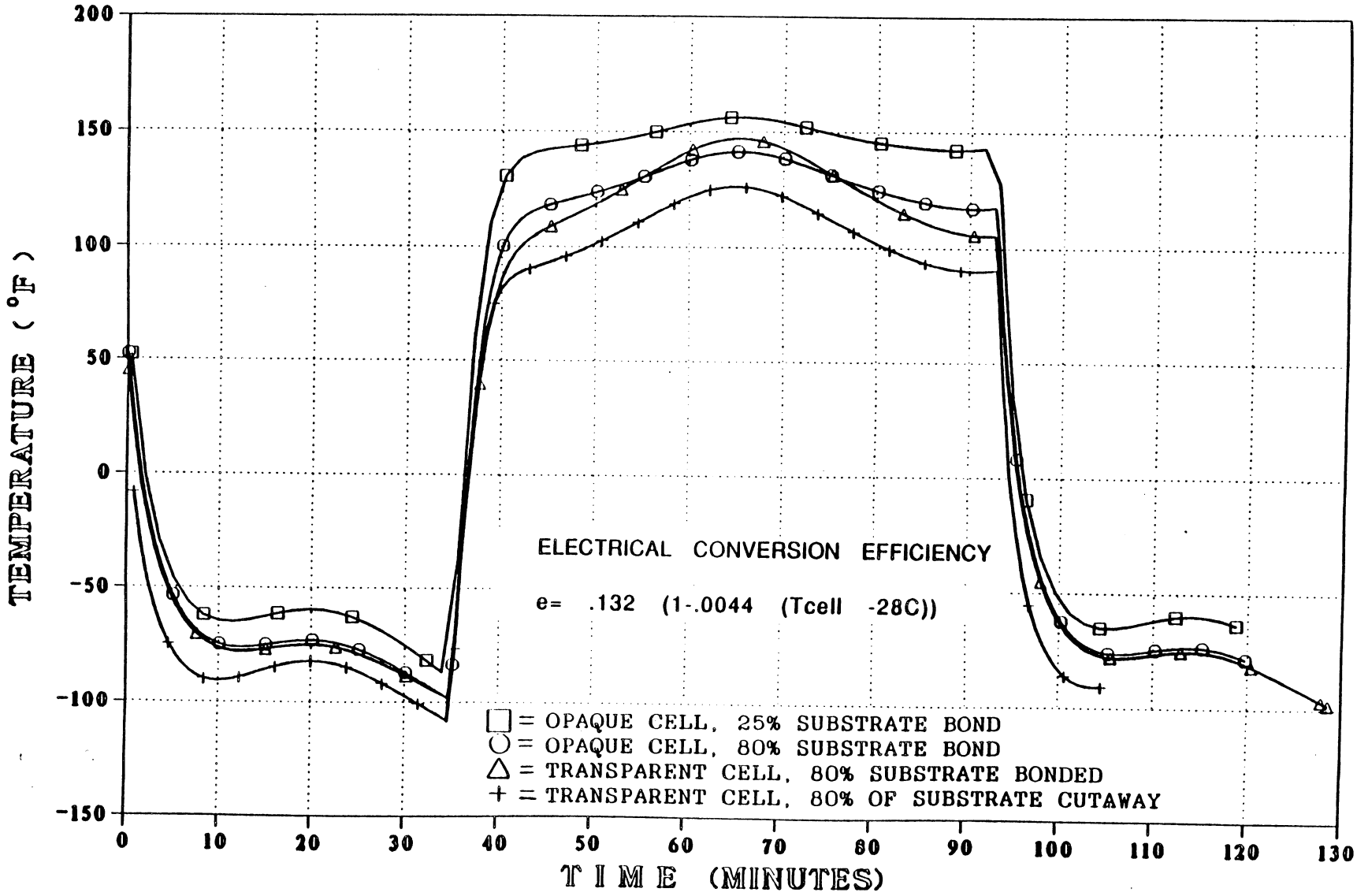
DESIGN CHANGES TO IMPROVE CELL THERMAL PERFORMANCE

- BOND SUBSTRATE TO CELL BACKFACE WHERE POSSIBLE
  - REDUCES RADIATION SHIELD EFFECT
  - ACRYLIC TRANSFER TAPE OR SILICONE ADHESIVE
- WITH CUTAWAY SUBSTRATE ADD COATING TO INCREASE EMMISSIVITY OF CELL BACKFACE
  - INCREASE EMMISSIVITY FROM 0.6 TO 0.85
  - TRANSPARENT TO SOLAR WAVELENGTHS

PREDICTED CELL TEMPERATURES ON ORBIT

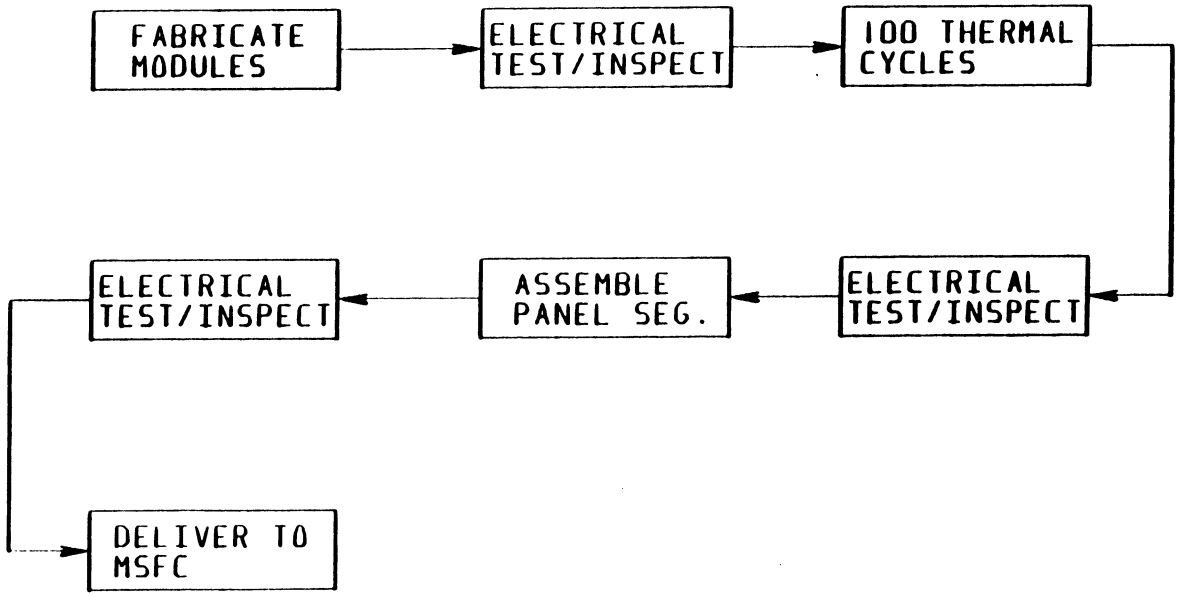
250 NM ORBIT, BETA ANGLE = 0 DEGREES

SOLAR LOAD NORMAL TO ARRAY

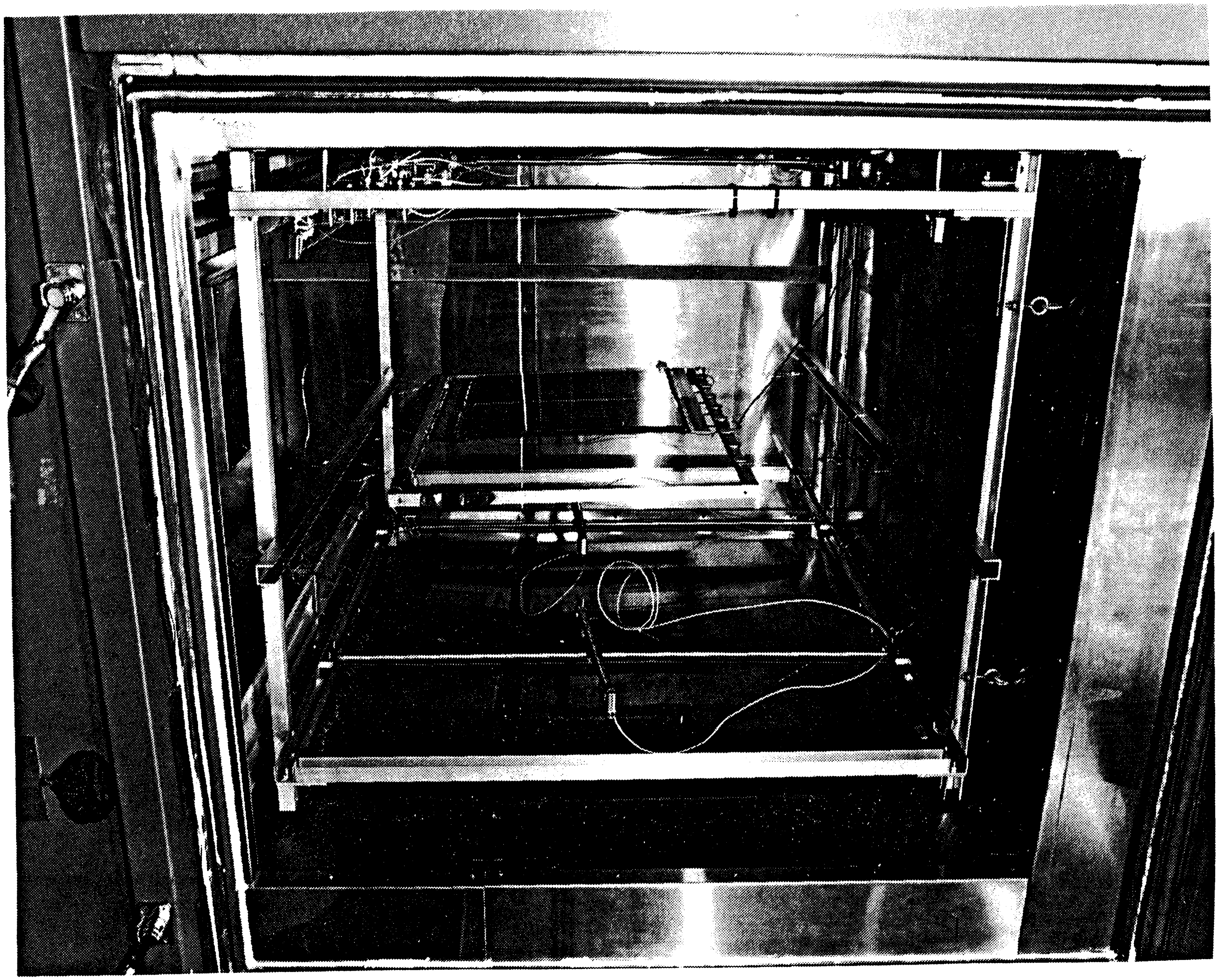


28-APR-87, *Thermodynamics*

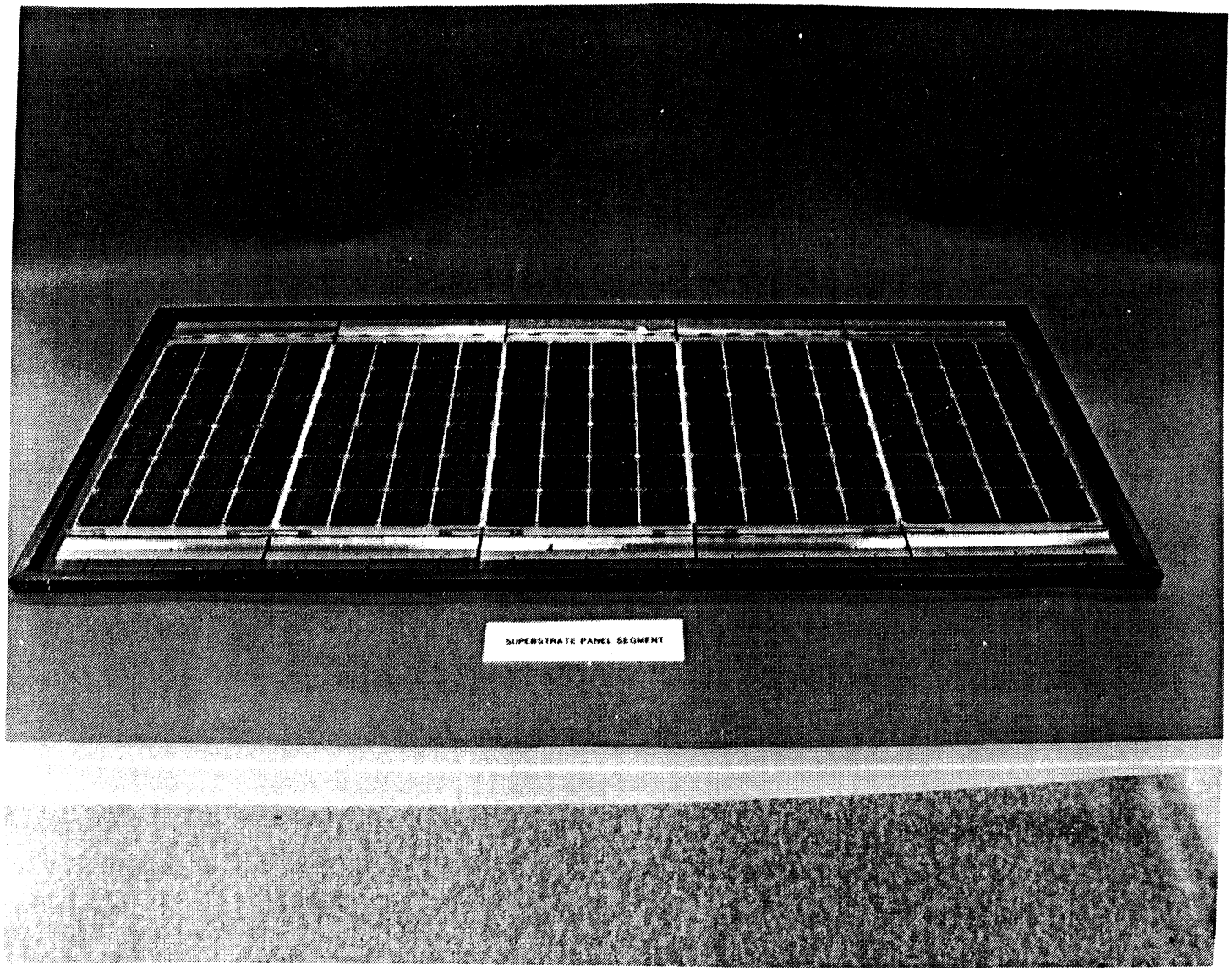
PANEL SEGMENT ACCEPTANCE TEST



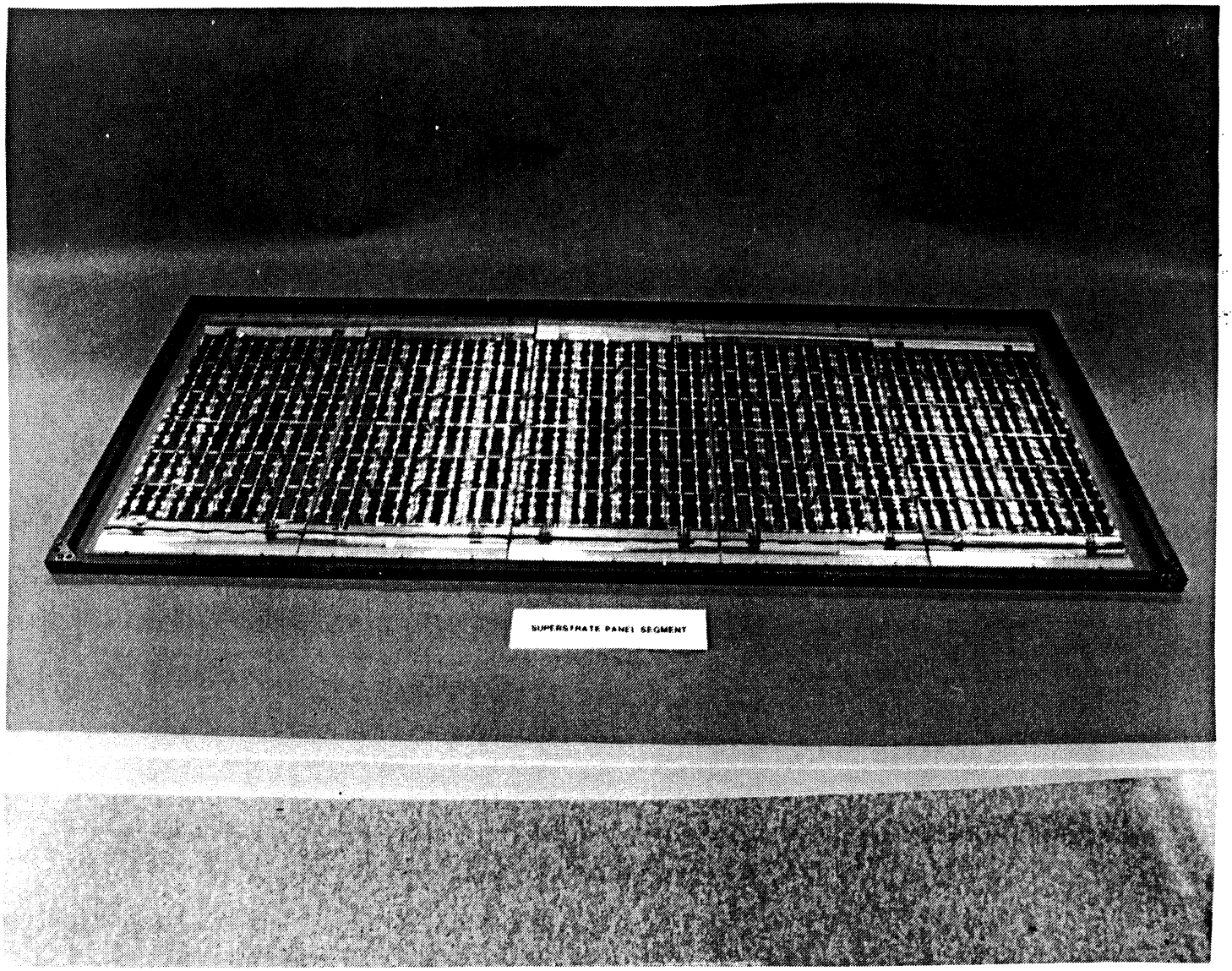
PANEL SEGMENT ACCEPTANCE TEST - FRONT SIDE



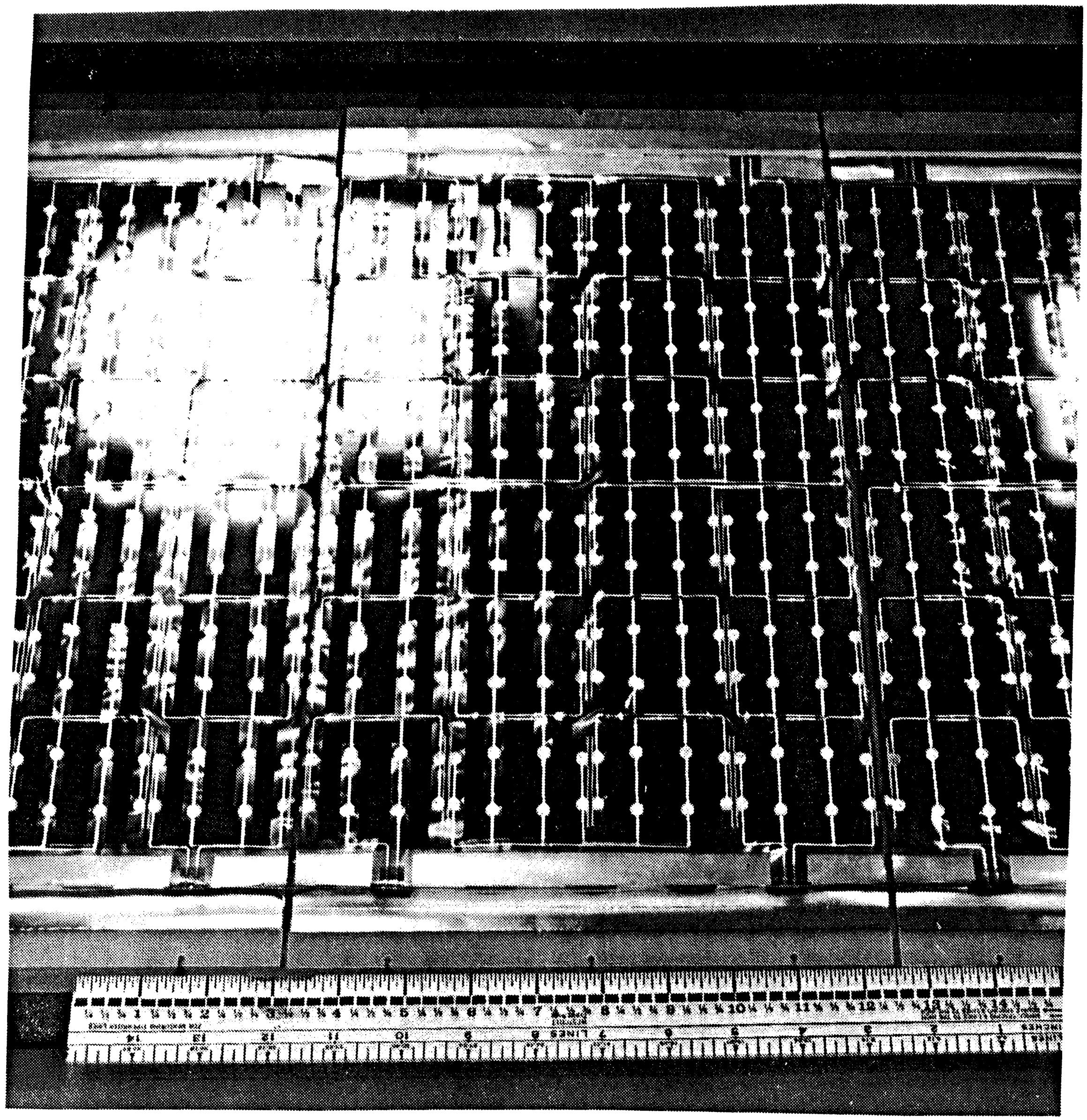
SUPERSTRATE PANEL SEGMENT - FRONT SIDE



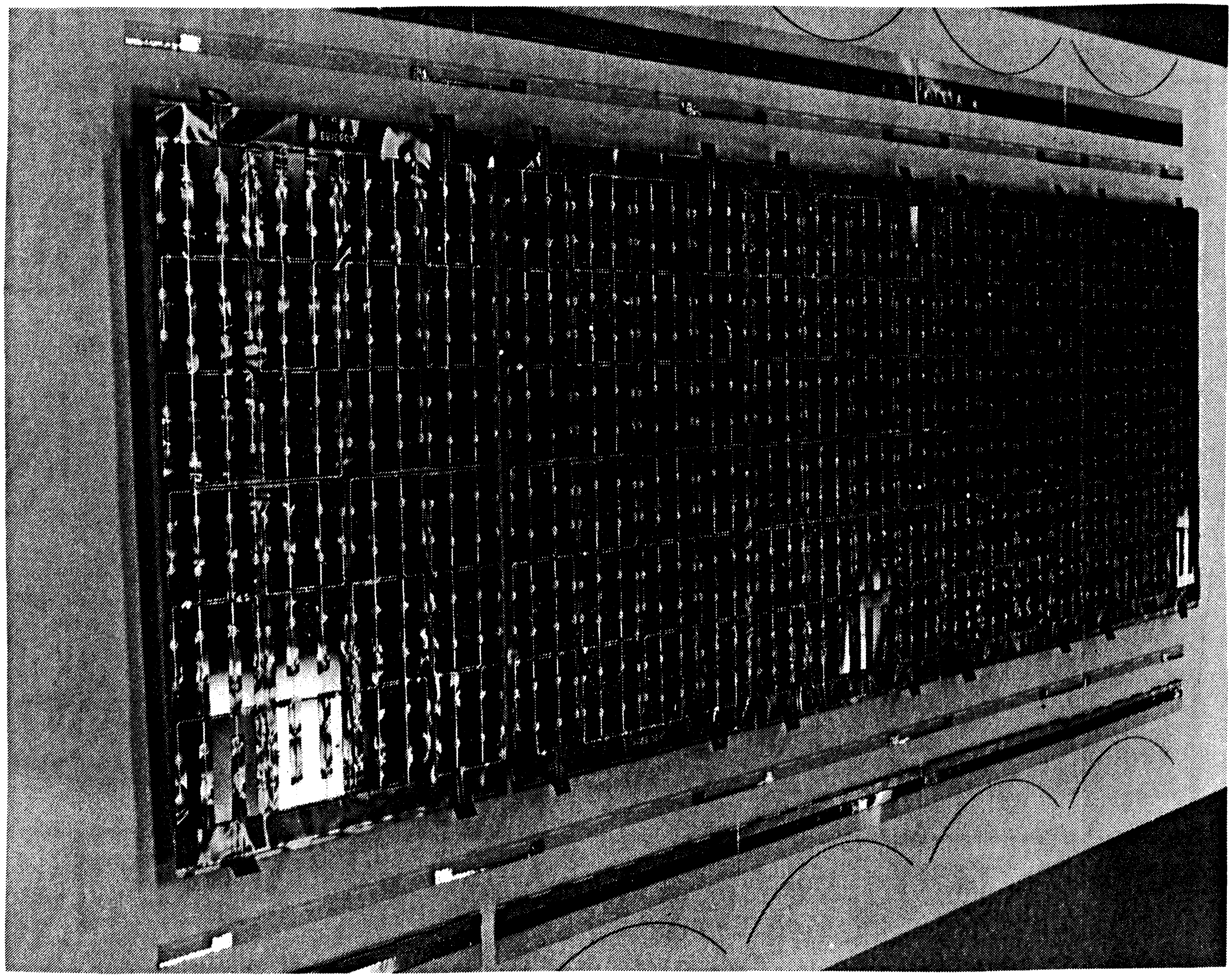
SUPERSTRATE PANEL SEGMENT - BACK SIDE



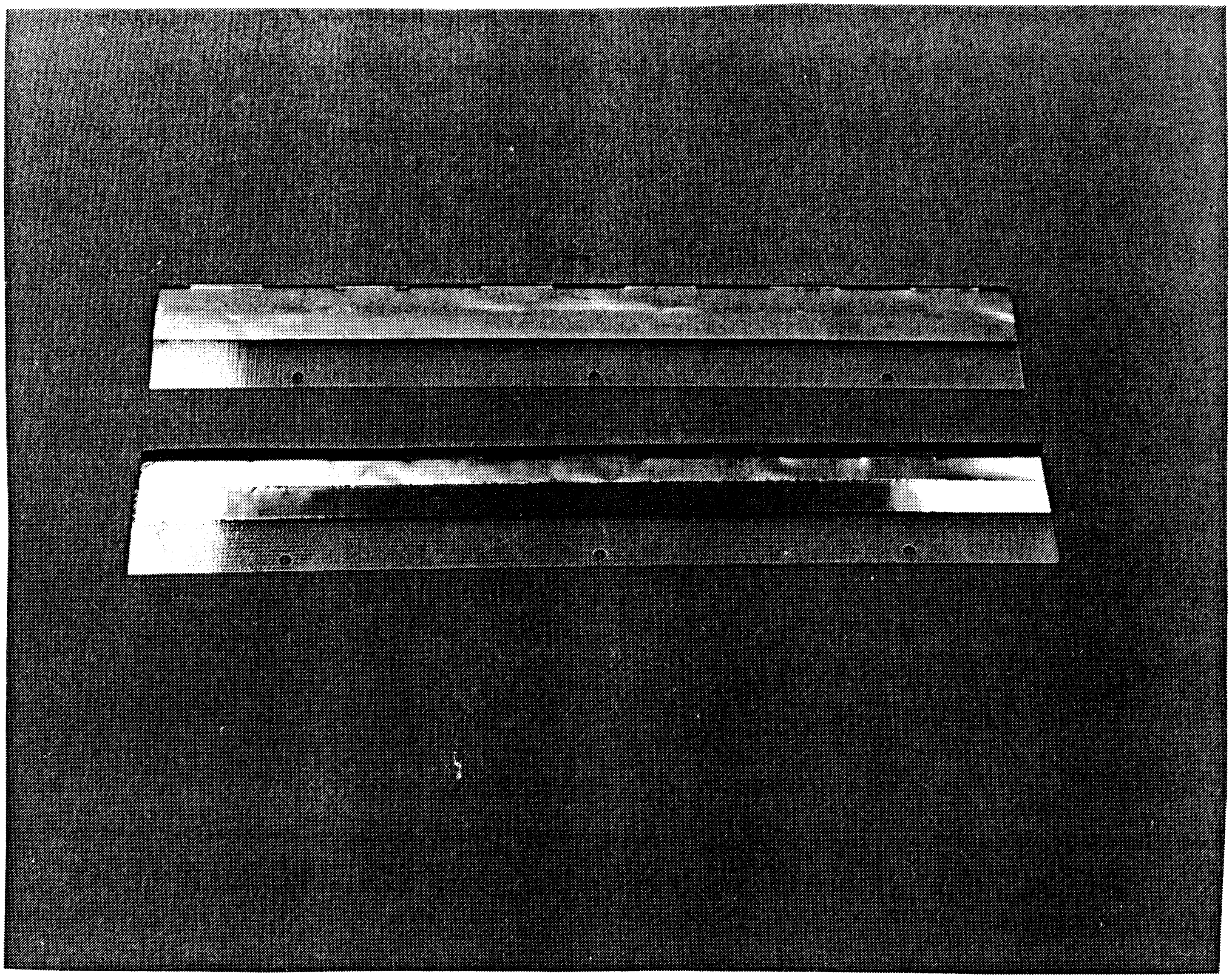
CLOSEUP OF COMPLETED SUPERSTRATE PANEL SEGMENT



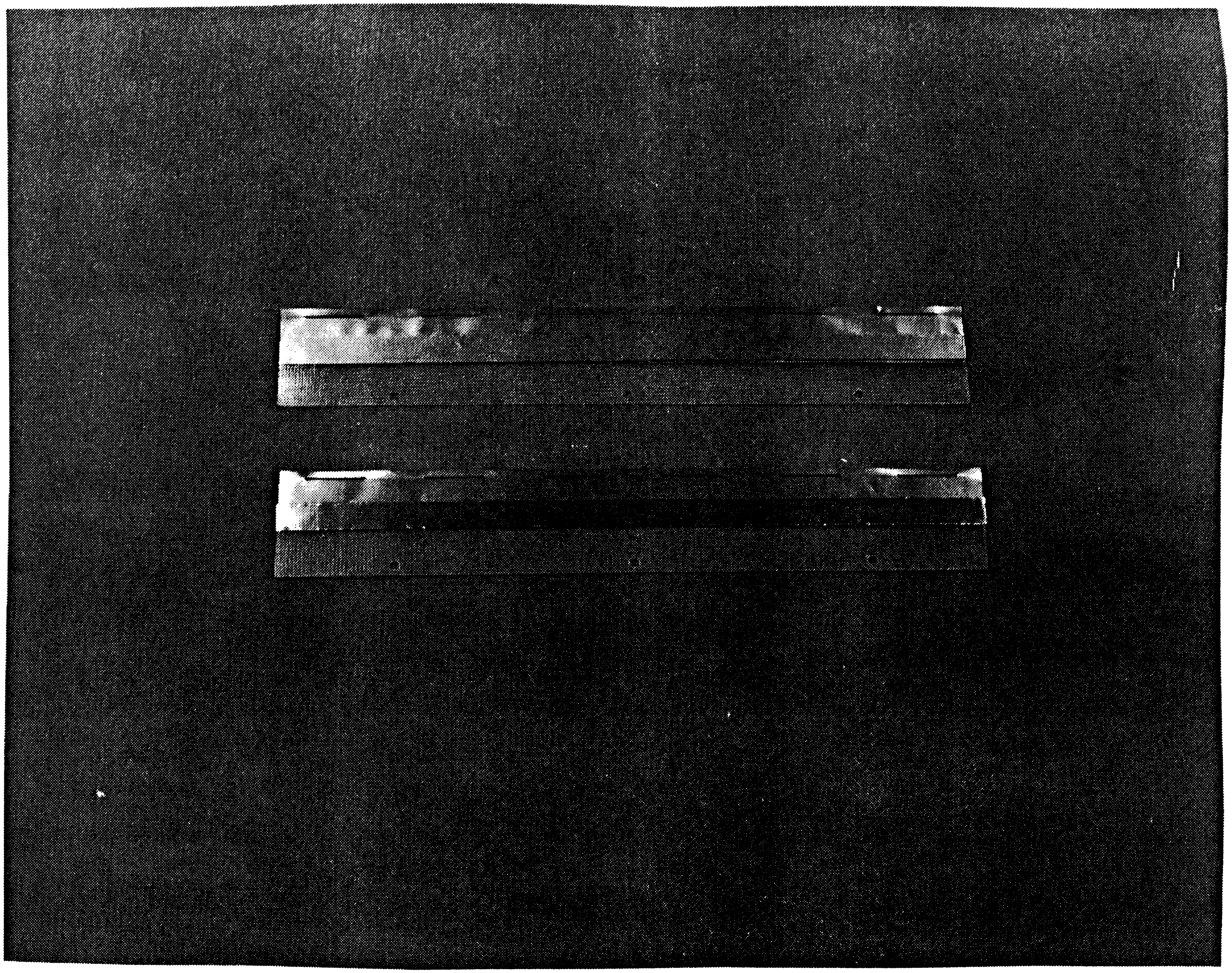
DISASSEMBLED SUPERSTRATE PANEL SEGMENT



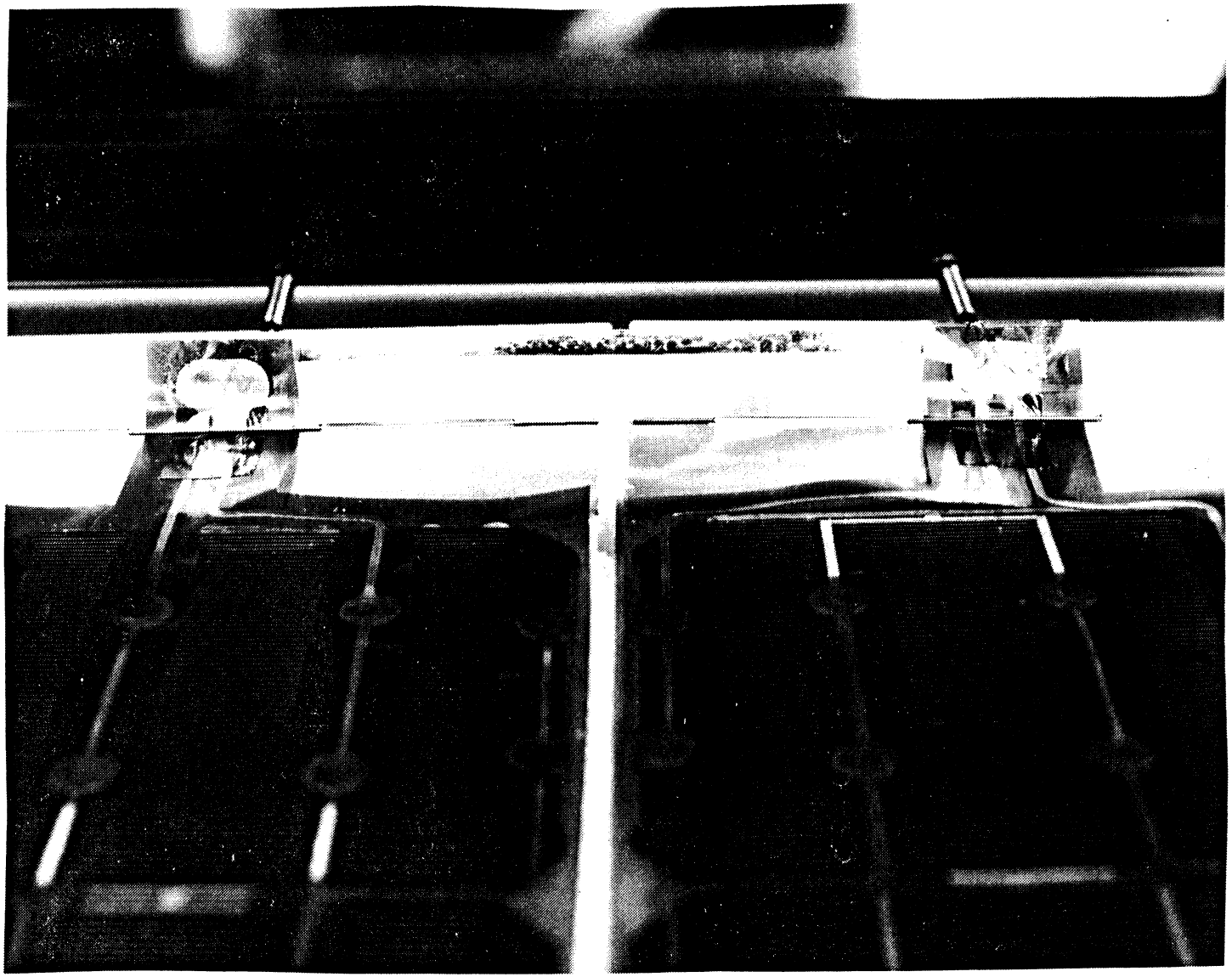
FORMED FIBERGLASS/MOLY HINGES FOR PANEL SEGMENT



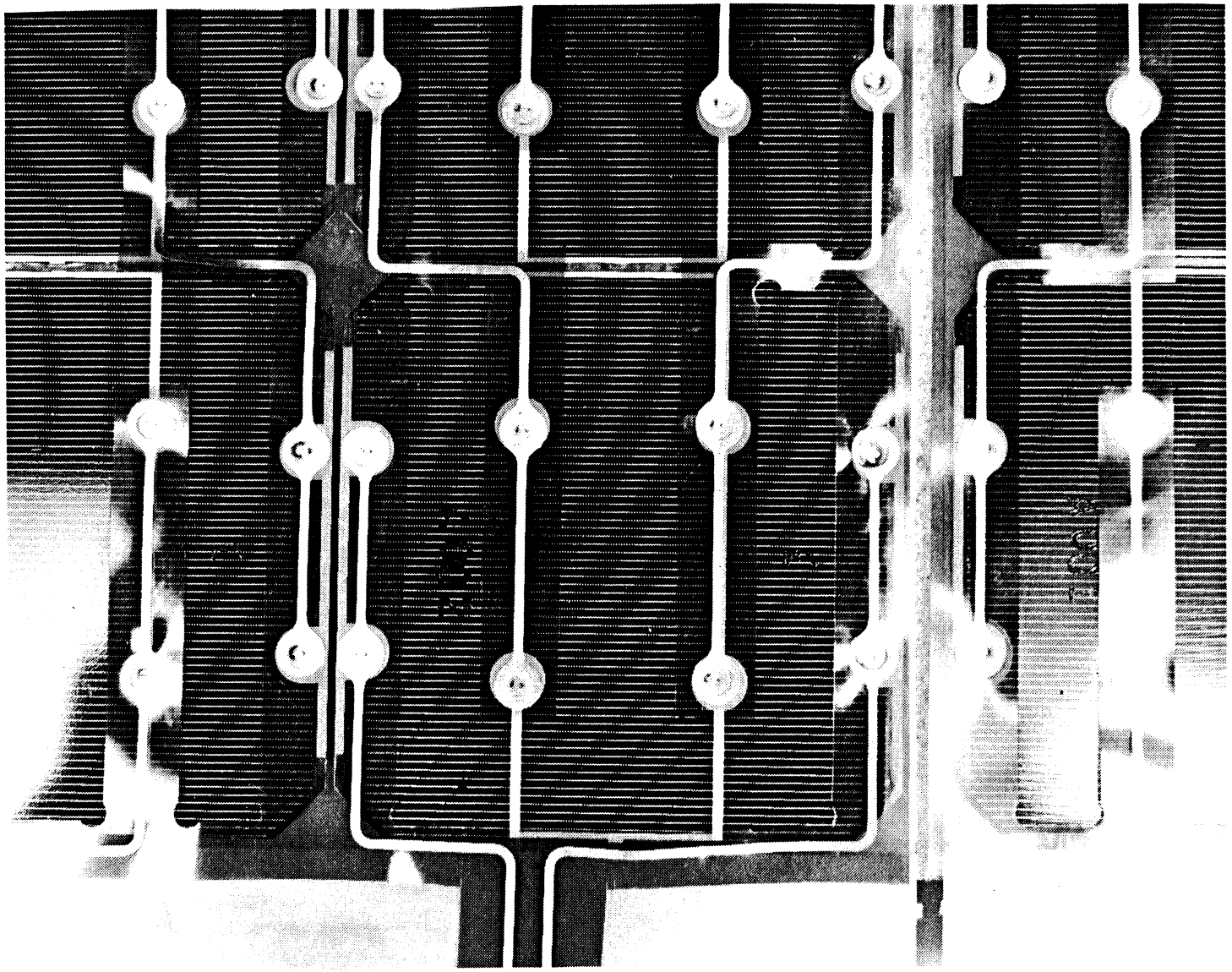
FIBERGLASS/MOLY HINGES FOR PANEL SEGMENT



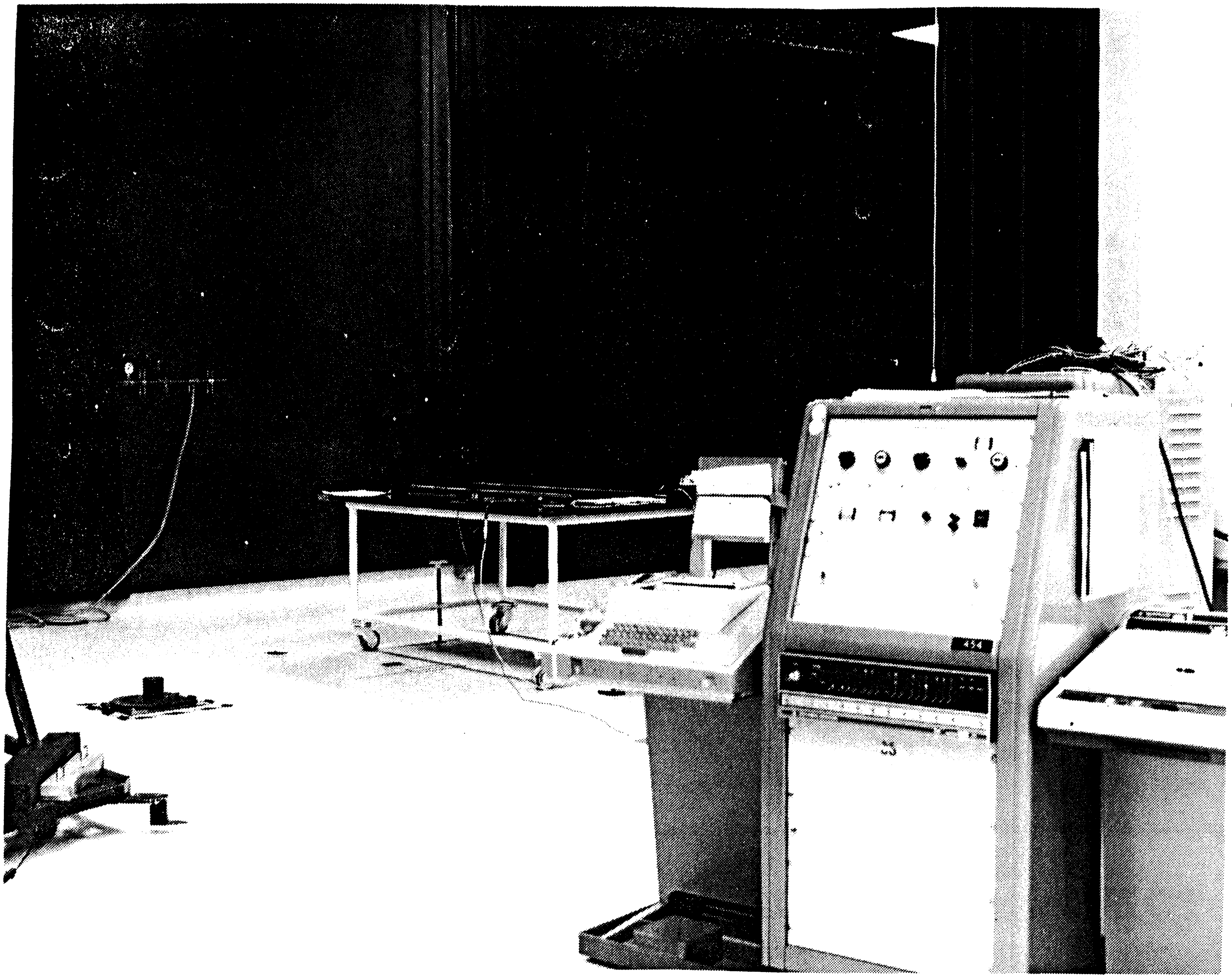
ELECTRICALLY CONNECTING TWO SUPERSTRATE MODULES WITH JUMPER - BACK SIDE



CLOSEUP OF CUT-AWAY KAPTON INTERCONNECT WELDED TO SUPERSTRATE ASSEMBLY



SETUP FOR ELECTRICAL TESTING OF PANEL SEGMENT



SUMMARY

- DEVELOPED PROCESS FOR MANUFACTURING SUPERSTRATE ASSEMBLIES
- FABRICATED TEN SUPERSTRATE MODULES AND TWO CONVENTIONAL MODULES
- THERMAL CYCLED THREE MODULES 2000 CYCLES IN LMSC'S "QUICK LOOK" THERMAL CYCLE CHAMBER
- PERFORMED THERMAL BALANCE TEST AT BOEING
- DELIVERED PANEL SEGMENT TO MSFC
- DETAIL DESIGN AND ANALYSIS OF SOLAR ARRAY WING CANCELLED UNTIL FUTURE FUNDS ARE AVAILABLE
- FABRICATION OF WING SEGMENT CANCELLED UNTIL FUTURE FUNDS ARE AVAILABLE

ADDITIONAL WORK

- COMPLETE REMAINDER OF TASKS FOR ADVANCED PLANAR ARRAY DEVELOPMENT FOR SPACE STATION (APADSS)
- INVESTIGATE EDGE PREPARATION TECHNIQUES FOR SUPERSTRATE GLASS
- INVESTIGATE USING SILICONE SHEET ADHESIVE (DC X4-46435) FOR SUPERSTRATE BONDING
- EVALUATE GLASS ENCAPSULATED SUPERSTRATE MODULES
  - PROTECTS AGAINST ATOMIC OXYGEN EROSION
  - LONGER THERMAL CYCLING CAPABILITY